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The Silica Dust Hazard in the Granite Cutting Industry

A Rational Expression for Wet Kata Cooling Power

The Quantitative Measurement of Human Efficiency under Factory Conditions
(Concluded)

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THE JOURNAL OF INDUSTRIAL HYGIENE

VOLUME XII APRIL, 1930 NUMBER 4

THE SILICA DUST HAZARD IN THE GRANITE CUTTING INDUSTRY*

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IN the past our knowledge of the effect of industrial hazards on the health of workers has been gained largely from occupational mortality statistics and the physical examination of sample groups of employees. It was believed that the dust hazard in this country offered an opportunity for an investigation of a more intensive character, by observing groups of workers over a period of time as to the character and severity of sickness which might be associated with the hazard.

In order to study the health of workers in the dusty trades, six specific investigations were undertaken, each dealing with a different type of dust.

* Received for publication Jan. 13, 1930.

A list of these dusts follows:

1. Calcium dust (Portland cement plant)[1]
2. Silica dust (granite industry)[2]
3. Metal and other dusts (silver polishing)
4. Carbon dust (hard coal mining)[3]
5. Vegetable dust (cotton milling)
6. Municipal dust (street sweeping)

Two papers in regard to the study of calcium dust have been published in

[1] Thompson, L. R., Brundage, D. K., Russell, A. E., and Bloomfield, J. J.: The Health of Workers in Dusty Trades. I. Health of Workers in a Portland Cement Plant. U. S. Pub. Health Bull. No. 176, 1928.

[2] Russell, A. E., Britten, R. H., Thompson, L. R., and Bloomfield, J. J.: The Health of Workers in Dusty Trades. II. Exposure to Siliceous Dust (Granite Industry). U. S. Pub. Health Bull. No. 187, 1929.

[3] Also a modified study in a soft coal district.

THIS JOURNAL.[4] The present article deals with the second investigation—the effect upon the worker of exposure to silica dust in the granite cutting industry. The plants in which the study was made were in Barre, Vt. It should be understood that this investigation was not one of the granite industry, or of the sanitary conditions or the environment of any particular plant or group of plants. It was a study of silica dust of a definitely known composition in its effect on the health of the workers.

A complete report of this study will be found in Public Health Bulletin No. 187. It was felt, however, that the results of the study justified a special summary for the purpose of THIS JOURNAL.

The investigation consisted of several phases. Physical examinations were given to as large a group of workers as possible, for the purpose of determining the general physical condition of the individual and of discovering any abnormal conditions, particularly with reference to lung pathology. In the fourteen plants where morbidity records were kept, 296 out of 972 persons were examined. In other plants in the same city, 207 examinations were made. Some examinations were also made of persons formerly employed in granite but at the time working in other industries, and of persons in the families of granite cutters.

In connection with the physical examinations about 250 X-rays of the chests of workers were taken. Every effort was also made to secure sputum analyses. Autopsies were performed in each instance where it was possible to obtain the family's consent.

A sickness record was kept for each person in the groups under observation. Arrangements were made with fourteen granite manufacturing plants whereby the names of workers who were absent would be reported daily. Regardless of its cause, the absence was investigated. Information was obtained from the patient as to the nature of his illness and the name of the physician treating him, if there was one. Record was also kept of the date of return to work.

In addition to a record of deaths occurring in the population under study, a transcript was made of all death certificates in the city from 1900 to 1925. An occupational analysis was made and in addition an extended study of the amount of dust in the air under different conditions, and its nature. The impinger dust collector was used.[5] Chemical and petrographic analyses of the dusts were also made.

OCCUPATIONAL ENVIRONMENT

Survey of Plants.—It is not necessary to review in any detail the results of the sanitary survey of the plants, but it should be pointed out that natural ventilation by means of numerous

[4] Thompson, L. R., and Brundage, D. K.: A Study of Exposure to Calcium Dusts Generated in the Manufacture of Portland Cement. THIS JOUR., 1929, *11*, 182.
Thompson, L. R., and Brundage, D. K.: Respiratory Diseases in a Portland Cement Plant. *Ibid.*, p. 266.

[5] Katz, S. H., *et al.*: Comparative Tests of Instruments for Determining Atmospheric Dusts. U. S. Pub. Health Bull. No. 144, 1925.
Greenburg, L.: Studies on the Industrial Dust Problem: III. Comparative Field Studies of the Palmer Apparatus, the Konimeter, and the Impinger Methods for Sampling Aerial Dust. U. S. Pub. Health Rep., 1925, *40*, 1591.

windows was solely depended on for the removal of dust, except in the case of sand blasters and inside surface cutters. On account of the severity of the climate, the windows were generally kept closed through a considerable part of the year.

Chemical and Petrographic Analyses of Dusts.—Silica forms 70 per cent. of the total constituents of granite. Two samples of granite dust were analyzed petrographically to determine the amount of free silica in the form of quartz, and the percentages were found to be 31.8 and 38.6. Samples were also analyzed for steel fragments which might have been worn away from the tools. These fragments constituted about 0.1 per cent.

Extent of Plant Dustiness.—A total of 220 dust determinations were made, some during the summer and some during the winter, in order to determine the extent of atmospheric pollution of granite cutting plants. The average dust counts for various occupational groups varied from 59.2 million particles per cubic foot for all hand pneumatic tool operators to 1.9 for office employees. On the basis of the amount of dust found associated with different occupations, the occupations were classified into four dust count groups as indicated in Table 1, which also gives the number of workers in each occupational group. This grouping was based entirely on the amount of exposure in the various occupational

TABLE 1.—CLASSIFICATION OF OCCUPATIONS INTO DUST COUNT GROUPS

DUST COUNT GROUP	OCCUPATION	NO. OF MEN	DUST COUNT	
			million particles/cu. ft. of air	
A	Hand pneumatic tool operators	565	59.2	
	Carvers and letterers	24	37.0	More than average plant dustiness.
	Part of employment in other occupations	25	....	
B	Surface machine operators	68	44.0	
	Tool grinders	20	27.1	
	Others	16	....	
C	Lumpers, Boxers, Polishers (all but plant A), Cranemen, Bed setters, Tool carriers, Mechanics, Laborers	146	20.2	Average plant dustiness.
D	Polishers (plant A)	18	9.0	
	Sand blast operators	4	6.2	Less than average plant dustiness.
	Sawyers	10	4.6	
	Blacksmiths	10	2.5	
	Others[1] (no specific dust count, but low)	66	....	

[1] Derrick men (22), engineers (10), machinists (9), etc.

groups without reference to the physical examination findings or the sickness record.

Practically no differences between summer and winter conditions as to dustiness were found in any of the occupations. This was due to the fact that in the summer time the dust removed by the ventilation systems was blown back into the plant through the open windows.

Two types of exhaust systems were in general use for surface cutting machines: (1) in which an individual blower was supplied with each machine; and (2) in which a large blower was used to remove the dust for from two to eight surfacers. The latter system was in more general use.

In comparison with the dust counts made in the other dusty trades studied by the United States Public Health Service, granite shows the highest average count except for hard and soft coal. Owing to the higher percentage of free silica as quartz, however, granite cutting was certainly first on the list so far as the magnitude of exposure and dangerousness to health were concerned. Table 2 gives the average

TABLE 2.—AVERAGE DUST COUNT IN CERTAIN DUSTY TRADES

INDUSTRY	DUST COUNT
	million particles/cu. ft. of air
Cement	26.0
Granite Cutting:	
Cutters	
Hand pneumatic tool operatives[1]	59.2
Others[2]	35.9
Attendant labor	17.0
Anthracite Coal Mining:	
Miners and miners' helpers	231.5
Attendant labor	31.1
Bituminous Coal Mining:	
Coal cutters and coal loaders	112.3
Attendant labor	3.9
Silverware Manufacturing:	
Rooms where dust is created	
Dusty processes	5.2
Non-dusty processes	1.7
Other rooms	0.8
Municipal Dust (Street Cleaners):	
Congested district	4.1
Residential district	1.8
Cotton Industry:	
Carding room	8.6
Weaving and spinning rooms	4.5

[1] Including 58 per cent. of all workers.

[2] Carvers and letterers included with other cutters (surface machine operatives, lathe operatives, and sand blast operatives).

dust count found in the various dusty trades in which these investigations have been conducted.

Factors Influencing Sickness Rates

Although the granite cutter remains in the industry for long periods, he frequently changes from one plant to another. Since only part of the Barre plants were included in this study of sickness, it was not possible to secure a record for the full period (two and one-fourth years) on all the workers who were in these plants. Accordingly, it was necessary to use as a basis for the calculation of rates not the number of persons, but the number of years for which any group was under observation. A year of observation would be either the record for a single individual for a year, or the record for several individuals for parts of a year, the sum of whose periods of observation as to sickness equals one year.

Physical Characteristics of Granite Workers.—The average height of granite workers was found to be 66.9 inches, or about the average in industry generally. The average weight of workers (taking the group employed in the industry less than ten years) was greater by several pounds than that of the general industrial workers of corresponding age. The group should therefore be considered as sturdy and not *per se* particularly susceptible to tuberculosis. Also, upon entrance into the industry the workers did not show any marked excess of serious impairment. Two manifest differences—the high rate for silicosis and the high rate for chronic rhinitis or pharyngitis—appeared to be associated with the dust hazard.

Length of Service in the Industry.—It was found that the granite workers remained in the industry longer than workers in general. In fact, 75 per cent. of the workers observed had been employed for ten years or more, whereas among industries included in other Public Health Service studies the percentage varied from 61 to 8. Of the various dust count groups, A and B showed the longest period of service.

Age Distribution.—As a result of the extended length of service, the age distribution of granite workers is relatively high. This fact is brought out in Table 3, which compares the age distribution of granite workers with that of industrial workers generally. In this and in succeeding tables, the numbers have been omitted to save space. They will, of course, be found in the complete report.

TABLE 3.—AGE DISTRIBUTION OF GRANITE WORKERS AND OF INDUSTRIAL WORKERS GENERALLY

	PERCENTAGE DISTRIBUTION BY AGE				
	Up to 20	20–29	30–39	40–49	50 and Over
Granite workers	4	19	26	33	19
Industrial workers generally[1]	5	32	33	19	11

[1] Pub. Health Bull. No. 162, p. 11, Table 2.

In view of the fact that granite workers remain in the industry for a long period of time, it was possible to express their age in terms of their length of service, the age being found on the average to be 20 years greater than the length of service.

Race and Social Conditions.—Eighty-three per cent. of the workers in the industry fell into five racial groups—American, Italian, Scotch, Spanish, and French-Canadian. The Italians were principally from northern Italy and the Swiss border. In general the groups are rather stable, tending to remain in the industry. Because of the relatively high wages paid, the general living conditions are above those of the average industrial population.

General Sickness Record

The morbidity records were commenced in plant A on April 1, 1924, and by April 15 were under way in all but a few plants (with a relatively small number of workers). The study closed on June 30, 1926, giving about two and one-fourth years of observation.

In the case of prolonged sickness it was customary for the plants to drop the workers from the payrolls after a certain interval, but for the purpose of this study sick workers were necessarily kept on the records until recovery and return to work or until death.

In this study 68 per cent. of the cases of illness lasted eight days and longer, whereas in the ordinary experience among industrial workers this percentage is from 35 to 40. The relatively small amount of short time illness is thought to be associated with the fact that the workers were employed for a relatively short week, five days in the summer and five and one-half days in the winter. Whatever the cause, it appeared that the clearest way of getting at the illness in this group was to consider for most purposes cases lasting eight days and longer. This facilitated comparison with general sick benefit records.

General Incidence by Cause.—Table 4 compares the frequency of absences due to specified cause among granite workers with that in four other industrial groups, the comparison being limited to cases lasting eight days and longer. The five industrial groups used in the table are:

1. Granite workers as observed in this study.
2. A group of gold miners in the West working in hard rock with a high silica content.
3. A group of cement workers as reported in Public Health Bulletin No. 176.
4. A group of workers in the iron and steel industry.
5. The general sick benefit experience of many industrial concerns, as reported periodically to the United States Public Health Service.

The high rate for tuberculosis among granite workers is the outstanding point of interest. The high rate for pleurisy is also significant. The rate for all causes for the granite group is much higher than the level of general sick benefit experience. For respiratory conditions the granite group is higher than any of the other groups compared; but there is no excess for nonrespiratory diseases.

In view of the fact that sickness records were obtained by comparable methods in all the dust studies, a further table (Table 5) is given for direct comparison among these studies. In this case sickness from respiratory conditions lasting for two working days or longer is used, and the annual rates are based on 100 instead of 1,000 years of observation.

This comparison shows that there is

evidently a difference in the nature of respiratory diseases occurring among persons exposed to different kinds of dusts. The hard coal industry and the cement plant have high rates for grip and certain other minor respiratory affections. In the soft coal industry, bronchial diseases and pneumonia are excessive; in the cotton industry, grip and diseases of the nasal fossae; in the granite industry, tuberculosis. Pleurisy is excessive in the granite and hard coal industries. The dusty occupations in silver polishing show no excess from any cause.

Incidence in Dust Count Groups.—In groups A and B the incidence rate for all causes (absences of eight days and longer) was about 215 per 1,000 years of observation; in group C, 105; and in group D, 61. The same striking difference was found for respiratory diseases, and even when the sickness from tuberculosis and suspected tuber-

TABLE 4.—COMPARISON OF FREQUENCY OF ABSENCES[1] DUE TO SPECIFIED CAUSE AMONG GRANITE WORKERS WITH FREQUENCY IN CERTAIN OTHER INDUSTRIAL GROUPS

CAUSE OF ABSENCE	RATE PER 1,000 YEARS OF OBSERVATION				
	Granite Workers	Hard Rock Gold Mining	Cement Workers	Iron and Steel Industry	General Sick Benefit
Sickness, exclusive of accidents	176.1	207.9	155.9	70.1	86.0
Respiratory diseases	120.4	107.4	89.1	33.2	40.1
Influenza and grip	34.2	65.6	59.0	16.7	18.4
Tuberculosis	37.1	10.0	1.3	1.4	1.5
Bronchitis (acute and chronic)	3.0	5.0	7.8	2.9	5.3
Pneumonia	4.5	3.1	1.3	4.9	3.3
Pharyngitis and tonsillitis	8.9	18.1	11.8	3.5	5.9
Other respiratory diseases	32.7[2]	5.6	7.9	3.8	5.7
Diseases of the digestive system	14.1	28.1	13.1	9.3	12.7
Diseases of the stomach, diarrhea, enteritis	3.7	11.2	3.9	4.6	6.1
Appendicitis	3.7	12.5	3.9	2.3	3.1
Other diseases of the digestive system	6.7	4.4	5.3	2.4	3.5
Diseases of the nervous system	8.2	12.5	5.2	3.9	5.7
Diseases of the circulatory and genito-urinary systems	6.7	8.1	10.5	5.4	6.1
Diseases of the skin	0.7	6.2	9.2	2.5	3.5
Rheumatism (acute and chronic)	4.5	15.6	13.1	5.1	5.5
Ill-defined diagnoses	9.7	1.9	1.3	0.6	2.3
All other diseases	11.9	28.1	14.4	10.1	10.1
Years of observation	1,346	1,602	763	89,305	336,525

[1] Lasting eight days and more.

[2] Diseases of the nasal fossae, 18.9; pleurisy, 11.6; asthma, 2.2.

culosis was eliminated, the respiratory rates were still higher for A and B than for C and D.

A somewhat higher rate of respiratory sickness was found among persons diagnosed as having silicosis than among those not so diagnosed. This difference is especially notable in illness due to colds and influenza.

TABLE 5.—SICKNESS[1] FROM RESPIRATORY CONDITIONS IN SIX DUSTY TRADES

DIAGNOSIS	ANNUAL RATE PER 100 YEARS OF OBSERVATION						NO. OF CASES					
	Granite	Cement	Hard Coal	Soft Coal	Cotton	Silver Polishing[2]	Granite	Cement	Hard Coal	Soft Coal	Cotton	Silver Polishing[2]
Asthma	0.2	....	0.4	....	0.9	0.4	3	..	4	..	7	3
Bronchitis	0.3	5.0	9.0	14.4	2.0	2.1	4	38	100	71	16	15
Pneumonia	0.5	0.4	0.2	1.0	0.2	0.1	7	3	2	5	2	1
Tuberculosis	3.7	0.1	0.7	....	....	0.1	50	1	8	..	..	1
Suspected tuberculosis	0.8	....	....	....	....		11	...	...	..	..	
Diseases of the nasal fossae	4.9	8.7	8.4	....	26.0	7.4	66	66	94	..	208	53
Influenza and grip	4.3	20.6	18.1	1.2	18.6	6.6	58	157	202	6	149	47
Pharyngitis and tonsillitis	0.7	7.5	5.7	4.7	2.9	0.7	9	57	64	23	23	5
Pleurisy	1.1	0.3	0.9	0.2	0.2	0.4	15	2	10	1	2	3
Other respiratory diseases	...	0.1	1.7	1.4	0.4	....	...	1	19	7	3	..
Total respiratory diseases	16.5	42.7	45.1	22.9	51.2	17.9	223	325	503	113	410	128
Years of observation	....	....	....	....	....	....	1,346	763	1,116	494	801	715

[1] Lasting two consecutive working days or longer.
[2] Males only, to agree with the other studies.

In Table 6 comparison is made by dust count group and length of service, for all causes. It is seen that the rate rises consistently with length of service in groups A and B but tends to decrease in groups C and D. The latter decrease is more or less parallel to normal morbidity experience. The rapid rise in the A and B groups reflects the presence of an industrial hazard.

It should be pointed out that even when persons with tuberculosis or suspected tuberculosis are excluded from the comparison, the rates are still higher in the A and B groups than in the C and D groups, and still show some increase with length of service.

TABLE 6.—INCIDENCE OF SICKNESS[1] FROM ALL CAUSES IN DUST COUNT GROUPS, BY LENGTH OF SERVICE

DUST COUNT GROUP	RATE PER 1,000 BY YEARS OF SERVICE			
	Up to 10	10–19	20–34	35 and Over
A	115.9	210.2	220.1	325.4
B	108.3	183.7	228.9	375.0
C and D	116.3	100.0	37.9	

[1] Lasting eight days and more.

Duration of Sickness.—The severity rates among granite workers were excessive, more than 16 days per person per year. For respiratory diseases this figure is 14.4, whereas the average number of days lost per person per year in industry is frequently less than 2. Because of the fact that nearly all of this disability is assignable to tuberculosis, severity of illness will be discussed in connection with that disease.

TABLE 7.—PERCENTAGE OF WORKERS WITH SICKNESS FROM CERTAIN CAUSES, BY DUST COUNT GROUPS AND LENGTH OF SERVICE

	PERCENTAGE BY YEARS OF SERVICE			NO. BY YEARS OF SERVICE		
	All	Less than 20	20 and Over	All	Less than 20	20 and Over
With any Sickness:						
A and B	41.4	34.5	45.4	99	30	69
C and D	20.3	26.2	9.1	26	22	4
With any Respiratory Sickness:						
A and B	30.5	21.8	35.5	73	19	54
C and D	14.8	19.1	6.8	19	16	3
With any Nonrespiratory Sickness:						
A and B	18.4	16.1	19.7	44	14	30
C and D	8.6	11.9	2.3	11	10	1
Persons:						
A and B	....	....	....	239	87	152
C and D	....	....	....	128	84	44

Percentage of Workers Sick during the Study.—It is appreciated that a confusing element is present in the rates which have been shown up to this point, owing to the necessity of dealing with the number of years of observation rather than with the number of persons. Therefore, an additional table has been prepared from the opposite point of view (Table 7). In this case it is necessary to deal with persons who were in the plants included in the morbidity study through the whole period, and therefore instead of including records based on 972 persons the table is limited to 367 persons.

The results are entirely consistent with what has been shown before. The occupational groups with highest exposure to dust show the largest percentage of persons who have been sick, whether the criterion be all illness, respiratory illness, colds, influenza, or nonrespiratory illness. Also, the percentage affected for the A and B groups generally shows the tendency to be higher among those with advancing length of service. This is not true in the C and D groups.

Sickness Prior to Development of Tuberculosis.—The rate of illness among persons who subsequently developed tuberculosis was nearly three times as high as among those who did not, the excess being found in nearly all diagnoses. This group suffered from a large number of ill-defined conditions, such as fatigue.

Absence from Causes Other than Sick-

ness.—Higher rates of sickness in dust count groups A and B could not be due to failure to classify as such, absences in groups C and D which were really due to sickness, since there was a much lower proportion of absence from causes other than sickness in these two groups.

Physical Examination Findings Apart from Silicosis and Tuberculosis

In view of the fact that it was possible to examine only a relatively small proportion of granite workers, the question arises as to how far the group examined is representative of granite workers as a whole. It was possible to test this point by comparing the sickness rates in the group examined with those for the other workers in the plants in which sickness records were kept. Table 8 gives the rate per 1,000, by length of service, in these two groups.

One immediately sees that the rates are very much higher in the group given physical examinations, but that the difference is not marked until after ten years of employment in the industry. No doubt the primary cause of this discrepancy in the group of workers who had been employed for long periods lay in the efforts to secure examination of all cases suspected of being tuberculous. Accordingly, some correction is possible by limiting comparisons to persons without tuberculosis or suspected tuberculosis.

Aside from silicosis and tuberculosis, a few points are of sufficient interest to be mentioned. For instance, the chest expansion of workers at the beginning of industrial life was about equal to that of workers generally, but after twenty years or more in the industry it was found to be much less than that of the average industrial worker, even when consideration is given to the group without actual or suspected tuberculosis. In the case of vital capacity, however, one is surprised to find that the values do not fall off any more rapidly than in the ordinary group of industrial workers. Although this statement is true of the averages, there were no doubt certain individuals whose vital capacity was markedly reduced as a result of exposure to dust.

It is perhaps somewhat surprising that bronchitis was not found frequently on physical examination, but

TABLE 8.—FREQUENCY OF ABSENCES[1] DUE TO SICKNESS AMONG WORKERS GIVEN PHYSICAL EXAMINATIONS AND AMONG THOSE NOT EXAMINED, BY LENGTH OF SERVICE

	RATE PER 1,000 BY YEARS OF SERVICE						
	Up to 5	5–9	10–14	15–19	20–24	25–34	35 and Over
With physical examination	171	187	459	335	247	408	526
Without physical examination	84	111	52	92	103	105	79

[1] Lasting eight days and more.

this fact confirms the results of the sickness records. The pathology of chronic bronchitis is a chronic infection of the bronchial mucosa and an ultimate thinning of the walls and dilatation of the bronchioles. The extensive fibrosis incident to silicosis is quite opposite to this condition.

son with the general industrial population.

Silicosis

Basis of Diagnosis.—The diagnosis as to the nature and extent of silicosis was made from the history and physical findings and was corroborated by

TABLE 9.—COMPARISON OF PERCENTAGE WITH NORMAL HEARING IN BOTH EARS AMONG GRANITE WORKERS, BY LENGTH OF SERVICE, WITH PERCENTAGE AMONG GENERAL INDUSTRIAL WORKERS OF CORRESPONDING AGES

YEARS OF SERVICE	GRANITE WORKERS	AGE	INDUSTRIAL WORKERS GENERALLY[1]
	%		%
Less than 5	89	Less than 25	90
5–9	75	25–29	87
10–14	70	30–34	84
15–19	54	35–39	79
20–24	58	40–44	74
25–29	35	45–49	67
30 and over	14	50–54	63
		55–59	56
		60 and over	50

[1] Pub. Health Bull. No. 162, p. 161.

There is a more rapidly increasing rate for defective hearing with increasing length of employment than is found for industrial workers generally. In fact, the contrast in later industrial life is so great that there seems no reasonable doubt of the relationship between defective hearing and granite cutting. Table 9 gives the percentage of granite workers with normal hearing in both ears, as compared with industrial workers generally.

Except for workers with tuberculosis, no differences were found in systolic or diastolic blood pressure in comparison with X-rays when they were obtainable. Apart from the X-rays, the main points on which the diagnosis of silicosis was made were the history of exposure to dust, record of the development of a nonproductive cough, and occasional pains in the chest which are incident to the development of pleurisy in relation to silicosis. In early cases there was generally a beginning of impairment in resonance and a diminished tactile and vocal fremitus, with diminished breath sounds; in more advanced cases, hyperplasia of the muscles of the chest, and evidences of still greater impairment in

resonance; and in the most advanced cases, evidences of consolidation. Tactile and vocal fremitus appeared to diminish in proportion to the length of exposure, and there was a general softening of all respiratory sounds.

Medical Findings.—In general, patients with silicosis appeared to be well nourished, and except in advanced cases, there was usually no evidence, on casual examination, of any impaired physical ability. Very early in silicosis there is a limitation in the expansibility of the chest. In some of the advanced cases the maximum chest expansion was 2 centimeters.

The principal complaint of workers with silicosis was dyspnea, which in the early stages was noticeable only on exertion. It increased in direct proportion to the exposure to dust.

Another common complaint was pains in the chest, usually of a transient nature. The pains are part of the development of pleurisy which is coincident with the progress of silicosis. When the condition is severe enough to cause loss of time from work, it is usually a sign of incipient tuberculosis. No case of pleurisy with effusion was found either on physical examination or in the sickness reports.

An additional important symptom was slight cough, usually without expectoration, and probably not of pulmonary origin, but resulting apparently from mechanical irritation of the upper respiratory tract.

Changes in breath sounds, together with impaired resonance, limited chest expansion, and changes in fremitus, were the most constant findings in these cases of silicosis. Tuberculosis or bronchitis as complications of silicosis produced râles, but in uncomplicated cases râles were absent. Toxemia was usually absent in silicosis uncomplicated by infection.

Findings Based on Examination of X-Rays.—The X-rays indicate that silicosis follows a rather definite form in its development. There was a general thickening of each hilum and of the trunk shadows, the latter being indicated by linear markings throughout. In advanced cases there was confluence of shadows, forming consolidations. Mottlings, frequently referred to by other investigators, were conspicuously absent in these cases of silicosis. The angles of the diaphragm were not always clear, particularly at the cardiac end, and the overlapping of thickened pleura also added to the densities in this region. Irregularities of the diaphragm were frequently observed, being present in 40 per cent. of the cases. It is evident from clinical and X-ray findings that a chronic pleurisy is a definite part of the pathology of silicosis.

Incidence by Length of Service.—The classification as to stages of silicosis used by other investigators (presilicotic, first stage, and second stage, or, as generally termed in America, first, second, and third stages) has not been found feasible in this study. In the first place, the X-ray findings indicate a different type of silicosis. Secondly, from a final consideration of the cases of silicosis from all angles, it was found practically impossible to classify the cases into definite stages, since the condition was one of progressive development. Thirdly, the diagnosis of silicosis in this study was not limited to examination of the X-rays alone, but was based on findings from the physical examinations and the X-

rays combined. Although no classification of individuals into stages has been attempted, it has been convenient for statistical purposes, however, to differentiate cases which were in their incipiency, and these have been termed "early."

It will be seen that practically 100 per cent. have cases of early silicosis after about four years' employment. After about nine or ten years of service nearly 100 per cent. have cases of silicosis which may be regarded as well established.

TABLE 10.—PERCENTAGE WITH SILICOSIS IN GROUP A, BY LENGTH OF SERVICE

STAGE OF SILICOSIS	PERCENTAGE BY YEARS OF SERVICE								
	½–1	1½–2	2½–3	3½–4½	5–6	7–8	9–10	11–12	13–14
Early	..	20	82	100	86	43	4		..
Well-developed	..	..	..	...	14	57	92	93	96

After a relatively short period of employment in the industry, hand pneumatic tool operators showed signs of silicosis. The percentage with silicosis during the first years in the industry is shown in Table 10. These percentages are based purely on the group of workers who were given physical examination. (See also Fig. 1.)

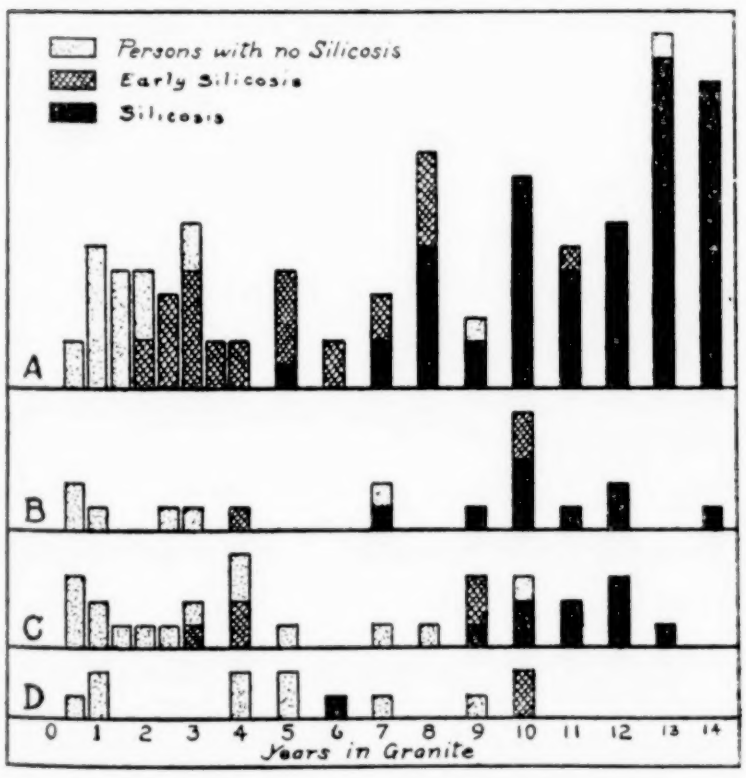


FIG. 1.—Persons without silicosis and those with silicosis in dust count groups, by length of service.

With respect to the other dust count groups, it may be said that the development of silicosis appears proportionate to the dust exposure. In group D, two cases of early silicosis occurred after ten years of exposure, and one case of established silicosis was found after six years of exposure.

X-Rays and Case Histories.—A large number of X-rays of granite workers were obtained, many of which are reproduced, together with detailed case histories, in Public Health Bulletin No. 187. None of these X-rays are reproduced at this time, since it is hoped that a special article dealing with them will later be prepared for THIS JOURNAL.

TUBERCULOSIS COMPLICATING SILICOSIS

The prevalence of tuberculosis was based on the proportion of persons found to have the disease, rather than on the incidence of the disabling illness resulting from it.

With accurate chest examinations and the use of laboratory methods in

the differential diagnosis, it was generally found possible in this study to differentiate between silicosis and silicosis complicated with tuberculosis. This was especially true in early silicosis; in advanced stages, on account of the enormous amount of pathology present, the diagnosis of tuberculosis was much more difficult. In cases of silicosis, tuberculous lesions, although abnormally located and generally found in the base of the lung, do not lose the definite and consistent signs found in tuberculosis. Practically no non-pulmonary tuberculosis was observed, except as associated with the pulmonary forms of the disease.

Type of Tuberculosis Found.—Two distinct groups of cases of tuberculosis were observed among granite cutters, the principal differences being found in the ages of the patients, the length of exposure to granite dust, the location of the lesions, and the course and prognosis of the disease. The first group—which forms the great majority of the cases—was comprised of workers who had a well-developed silicosis. The average age of these workers was 49; the average length of dust exposure, twenty-eight years. In this group, in contrast to the second group, the onset of the disease was rather sudden, and its course rapid, with fatal termination. The general location of the tuberculous lesions was basal. There were no periods of quiescence in any of the cases which came under observation, nor were there any recoveries. The second type of tuberculosis observed, which has been termed concurrent silicosis and tuberculosis, resembled the disease in persons not exposed to dust. In this group of cases the lesions were usually located in the apexes, and the course of the disease was slower. The ages of the group ranged from 24 to 38 years, averaging 31 years, and the length of exposure to dust was from three to thirteen years, averaging eight years.

Institutional treatment appeared to have no effect in retarding the development of the disease. Patients were perhaps more comfortable and obviously were less of a menace to their families and to the public, but the course and the prognosis of the disease did not appear to be altered.

Basis of Diagnosis.—The physical signs which were taken as a basis of diagnosis of tuberculosis complicating silicosis were unilateral limitation of expansion, areas of dulness in addition to the general impaired resonance already existing, increase of tactile fremitus over the tuberculous lesion, change in breath sounds where cavity formation existed, and, in many cases, bronchial breathing near the tuberculous lesion. The last-mentioned diagnostic sign was much less conspicuous because of the diminished breath sounds resulting from the silicosis. The presence of râles was an almost constant finding in cases of tuberculosis, and these were of the latent or post-tussic type. These physical signs considered in connection with the clinical symptoms of the patient were the main points upon which diagnosis was made.

Sputum Analyses.—Sputum analyses in cases of tuberculosis complicating silicosis showed that out of a total of 35 cases, 27 were positive, with bacilli present in the first specimen in 20 cases, in the second specimen in 4 cases, and in the third specimen in 3 cases. With an average of approximately two tests per person, about half the active

(excluding early) tuberculous cases gave a positive result. These findings taken in connection with the findings of the Vermont State Sanitorium (for early cases only), which showed that 76 out of 88 granite workers had tubercle bacilli in the sputum, and with the records of the Washington County Hospital at Barre, which showed that out of 34 cases only 1 gave a negative test, indicate that in the great majority of instances, at least, the diagnosis of tuberculosis as a complication of silicosis made from the diagnostic signs, symptoms, and X-rays was correct, and accordingly that deaths from silicosis uncomplicated by tuberculosis did not occur in this study.

tuberculosis among those given physical examinations gave an additional 3.8 per cent. It has been brought out previously that these prevalence figures represent the number of cases found over a period of two and one-fourth years and for this reason are greater than what would be obtained out of ordinary cross-section surveys. Table 11 presents the number of cases found, together with the mortality from tuberculosis occurring during the study. These figures are limited to the plants carrying morbidity records and the percentages are based on the total number of persons in these plants.

The percentage of workers found to have tuberculosis during the course of

TABLE 11.—ANALYSIS OF CASES DIAGNOSED AS TUBERCULOSIS ON PHYSICAL EXAMINATION

	PER-CENTAGE	NO.
Active Tuberculosis (except "Early"):		
Total	5.66	55
With known positive sputum	2.78	27
Died of Tuberculosis during Study:		
Total	2.57	25
With known positive sputum	1.13	11
Died of Tuberculosis after Close of Study:[1]		
Total	1.65	16
With known positive sputum	0.93	9
Early tuberculosis	0.82	8
Suspected or latent tuberculosis	3.82	37
Others with sickness termed "fatigue"	0.72	7
Total workers in plants carrying sickness records	....	972

[1] Approximate.

General Incidence.—In plants carrying morbidity records (where it was believed certain that all cases of tuberculosis were diagnosed as such) the general incidence rate was 5.7 per cent., or 6.5 per cent. if early cases are included. Latent or suspected cases of the study is not of any great meaning, because of the short duration of cases prior to death. Six per cent. is, of course, very high in comparison with what would be found in any usual industrial population; but it fails to represent the heavy toll of tuberculosis

in this group. Had cases survived for a longer period, the percentage would have been much higher.

Incidence by Age.—The age curve of pulmonary tuberculosis among granite workers was found to be greatly different from that in the general population. The characteristic high point in middle life has disappeared, and instead the curve rises steadily to the end of life. The prevalence by age is given in Table 12 for the plants carrying morbidity records.

TABLE 12.—PREVALENCE OF TUBERCULOSIS BY AGE

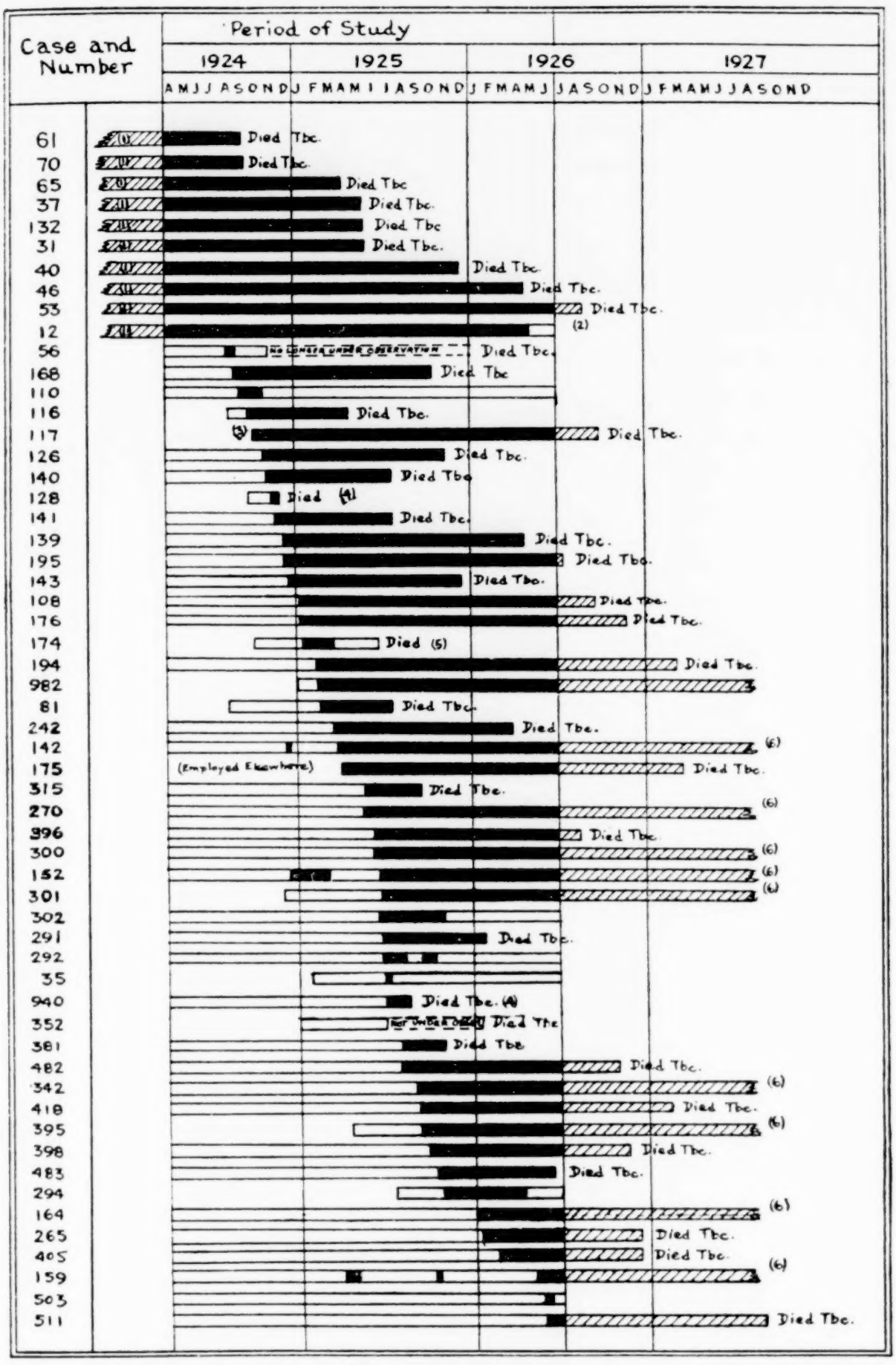
AGE	PERCENTAGE			NO. OF CASES			NO. OF PERSONS
	Total	Active Only	Suspected or Latent	Total	Active Only	Suspected or Latent	
Under 20	....	....	....	..	..	..	37
20–24	2.4	....	2.4	2	..	2	82
25–29	5.1	3.1	2.0	5	3	2	98
30–34	6.7	1.0	5.7	7	1	6	105
35–39	8.4	3.5	4.9	12	5	7	143
40–44	6.9	5.2	1.7	12	9	3	173
45–49	17.1	12.3	4.8	25	18	7	146
50–54	19.6	14.1	5.4	18	13	5	92
55–59	26.2	19.7	6.5	16	12	4	61
60 and over	9.1	6.1	3.0	3	2	1	33
All ages	10.3	6.5	3.8	100	63	37	970

Incidence in Dust Count Groups by Length of Service.—The relationship between tuberculosis as found in this study and the dust hazard may be shown very specifically by a comparison of the prevalence rates in the dust count groups, especially in relation to length of service. No cases of tuberculosis were found among persons classed in group D (*i.e.*, the group of occupations with less than the average plant dustiness). Group C showed three cases, but the first two occurred with less than ten years' employment in the industry and are apparently not associated in any marked degree with the dust. On the other hand, in groups A and B the prevalence rates rose rapidly with an increasing length of employment. The rates for the active cases are given in Table 13.

TABLE 13.—PREVALENCE OF ACTIVE TUBERCULOSIS IN DUST COUNT GROUPS, BY LENGTH OF SERVICE

DUST COUNT GROUP	PERCENTAGE BY YEARS OF SERVICE				
	Up to 10	10–19	20–24	25–34	35 and Over
A	0.8	2.0	10.2	15.1	15.5
B	...	4.8	7.1	19.1	
C[1]	3.5	1.1			
D	...	...	....	....	....

[1] Three cases in all.



(1) Disability began before April 1, 1924. Cases arranged in accordance with date of death.
(2) Arrested case.
(3) Not under observation until 1925, but diagnosed as having active tuberculosis on Oct. 1, 1924
(4) Cause of death tuberculosis and tuberculous meningitis.
(5) Pneumonia immediate cause of death.
(6) Lost track of because of leaving city.

FIG. 2.—Duration of disability from active tuberculosis, according to date of onset.

Since a record of disability was obtained in this study, it was possible in many instances to determine the length of time from the beginning of disabil-

ity until death from tuberculosis. A rather striking picture is presented in Figure 2 in which the individual cases of tuberculosis are taken up chronologically. The black portion of the bars shows the periods during which the individuals were disabled from tuberculosis during the study, and the crosshatched portion represents disability before the study opened or after it closed. No cases of sickness merely suspected of being tuberculous in nature are included.

What would be desirable in summarizing this graph is the average duration of the cases from the time disabling sickness began until death. Although no precise mean can be obtained so long as any of the cases remain alive, it is possible to obtain the median duration (or central item in the arrayed series) knowing that all cases which were still alive at the time that this paper was in preparation have a duration greater than the median. Such an average (leaving out of consideration cases lost track of because they left the city) yields fifteen months, the calculation being based on forty persons. Taken in conjunction with the absence of quiescent cases and the failure of cases to recover, this median is extremely significant. Out of the forty persons who died, thirteen lived for less than one year from the beginning of disabling sickness, and five for less than six months. The conclusion is accordingly justified that the course of the disease among granite workers is comparatively short.

With respect to the amount of disability due to tuberculosis, Table 14 has been prepared to show the number of days lost per person per year in the four dust count groups, by length of service. It will be seen that for the hand pneumatic tool cutters who have been in the industry for more than twenty-five years, an average of about thirty-one days per person per year was lost from this cause.

TABLE 14.—DAYS LOST FROM ACTIVE TUBERCULOSIS IN DUST COUNT GROUPS, BY LENGTH OF SERVICE

DUST COUNT GROUP	DAYS LOST PER PERSON PER YEAR, BY YEARS OF SERVICE		
	Up to 10	10–24	25 and Over
A	0.3	11.7	31.4
B	...	8.1	19.9
C	0.6	8.5	
D	...	....	....

Mortality.—Since the period for which deaths were collected covered about three years (information in regard to certain cases was secured after the close of the study), and since the population in the plants carrying morbidity records was accurately known, it was possible to calculate an annual death rate. This rate for tuberculosis alone was 14.1 per 1,000 workers, a rate which is in excess of the death rate for all causes in the general population and, of course, very much in excess of the corresponding rate in an ordinary industrial population. A sufficient number of deaths occurred to make it possible to compare the rate of mortality by dust count group and length of service, which is done in Table 15.

When one recalls that the rate of mortality according to age in the general

population is relatively uniform among adults, the interpretation of the data from this table is unmistakable. In groups A and B the mortality rate rises very rapidly with age. In groups C and D but one death occurred. This worker was a lumper who had been employed in the occupation for eighteen years.

TABLE 15.—DEATH RATE FROM TUBERCULOSIS IN DUST COUNT GROUPS, BY LENGTH OF SERVICE

DUST COUNT GROUP	ANNUAL DEATH RATE PER 1,000, BY YEARS OF SERVICE					
	Total	Up to 10	10–19	20–24	25–34	35 and Over
A	19.5	2.7	2.2	28.6	33.6	42.3
B	12.8	...	...	....	10.4	66.6
C	2.3[1]	...	...	....	....	....
D	.....	...	...	....	....	....

[1] One case, therefore no rates worked by length of service.

Figure 3 is of interest as summarizing both the morbidity and the mortality results.

X-Rays and Case Histories.—As in the section on silicosis, it is necessary to make reference to Public Health Bulletin No. 187 for detailed case histories and X-rays.

Course of Silicosis among Workers No Longer Exposed to Silica Dust

Because of the interest and difference of opinion which exists as to the health of granite workers who have left the industry and gone into other occupations, special effort was made to obtain histories of such persons. In all, twenty-four histories were obtained, and eighteen discussed, of workers who had carried on various non-dusty occupations for a number of years since exposure to granite dust. In eleven of the cases X-rays were obtainable. All cases showed evidences of silicosis

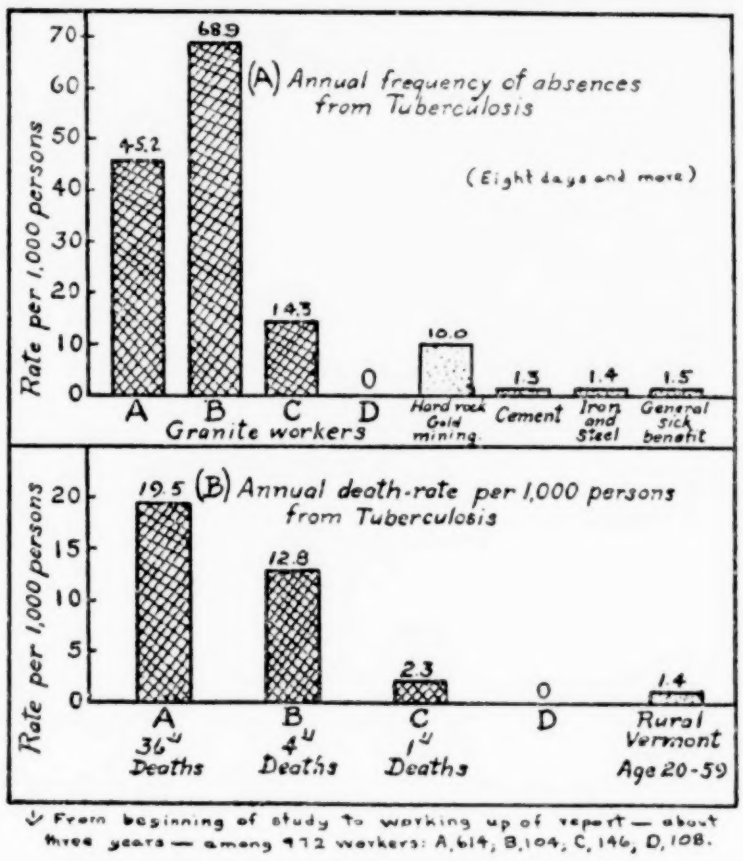


FIG. 3.—(A) Annual frequency of absences of eight days and more from tuberculosis. (B) Annual death rate from tuberculosis per 1,000 persons.

at the time of the examination, and in four the condition was in a more or less advanced stage. Again, of these eleven cases six were diagnosed as having active tuberculosis and one was a suspicious case. The seven workers for whom no X-rays could be obtained were diagnosed as having silicosis with tuberculosis and all of them died prior to the termination of this study. The average length of time that this group had been employed in other industries since leaving the granite industry was about eight and one-half years.

Autopsy Studies

Pathologic study was made of eight pairs of lungs from employees in the

granite industry. The results are not of such a nature as to permit a short summary, and therefore discussion will be deferred for a further paper to be submitted to THIS JOURNAL dealing specifically with this subject.

MORTALITY AMONG GRANITE WORKERS AS INDICATED ON DEATH CERTIFICATES

Transcripts were secured from death certificates for all cases appearing in the population among whom these deaths occurred. It was therefore necessary to deal with the percentage of deaths due to tuberculosis (proportionate mortality) in analyzing the material from the standpoint of occupation.

A detailed analysis of the death certificates has been included in Public Health Bulletin No. 187 and it does not seem necessary to reproduce the comparisons in this paper.

TABLE 16.—COMPARISON OF PERCENTAGE OF DEATHS DUE TO TUBERCULOSIS IN GRANITE INDUSTRY, 1900 TO 1925, WITH PERCENTAGE AMONG OCCUPIED MALES GENERALLY, 1908 AND 1909

OCCUPATION	PERCENTAGE DUE TO TUBERCULOSIS	NO. DUE TO			
		All Causes[1]	Pulmonary Tuberculosis	"Phthisis"	Other or Unspecified Tuberculosis
Cutters	65.6	631	327	60	27
Other granite workers[2]	45.0	158	62	6	3
Lumpers	52.0	25	12	1	..
Manufacturers and dealers	50.0	58	26	2	1
Polishers	40.5	37	12	2	1
Grinders	31.3	16	5	..	..
Quarry workers	16.7	24	2	..	2
Others[3]	39.1	23	7	1	1
Occupied males, registration area, 1908 and 1909	17.1[4]	353,153	60,492		..

[1] Except external.

[2] Excluding quarry workers.

[3] Tool carriers, bed setters, sawyers, etc. Eight is maximum in any one occupation. Derrick men work outside, yet five out of eight deaths in this occupation were due to tuberculosis, suggesting that the men had not always been in an atmosphere free from granite dust.

[4] Pulmonary only.

Barre from 1900 to 1925. Although the occupations of the persons dying and the causes of death could be obtained with some accuracy, no information was available as to occupations of

One fact that stood out, however, seems to require mention: namely, the presence of a high proportionate mortality from tuberculosis among granite workers who were not cutters, that is,

a group which in this investigation has been classed as being exposed to average plant dustiness or less and which appears not to have been adversely affected by the dust. Table 16 is given to bring out this difference.

It will be seen that lumpers have a proportionate mortality of 52; manufacturers and dealers, of 50; polishers, of 40.5; grinders, of 31.3; "others," of 39.1. So far as manufacturers and dealers are concerned, the excess mortality can be ascribed to the fact that

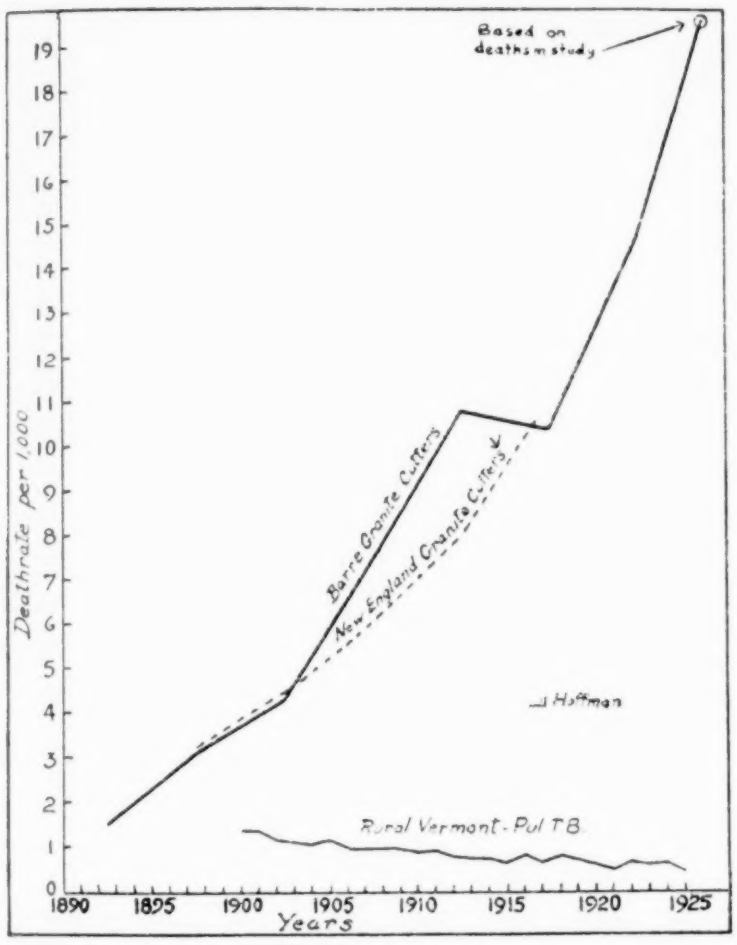


FIG. 4.—Comparison of trend of mortality from tuberculosis among granite cutters with trend among rural Vermont males.

most of them had formerly been granite cutters. With respect to the other occupations, the excess may be due to the fact that conditions in previous years were less favorable than at the present time, or it may be due to confusion in the statement made to the attending physician, or to a transfer from one occupation to another within the granite industry. At the same time the possibility remains that in spite of the findings given previously, a certain hazard exists with respect to occupations exposed only to the dustiness of the general plant atmosphere. The trend of mortality from tuberculosis among granite cutters is portrayed in Figure 4.

GENERAL COMMENTS

In summarizing the material which has been presented in this paper, it appears most feasible to quote directly from Public Health Bulletin 187:

The most important contribution of this study has been a picture of what happens to men working for many years under a dust hazard of a known character.

The significant features of this picture are:

a. The long period of service before the liability to tuberculosis becomes manifest (generally twenty years or more).

b. The sharp correlation between length of exposure to the dust and the prevalence of tuberculosis and also the death rate from this disease.

c. The close relation between extent of dust exposure and health of the men.

d. The universal occurrence of silicosis among the workers.

e. The large proportion of workers finally succumbing to tuberculosis.

f. The almost invariably fatal form of the disease within a short time after the onset.

g. The different character of silicosis as manifested by X-rays compared with that shown where there is exposure to a dust with a much higher content of free silica.

h. The location of the tuberculous lesion, usually basal, where the disease complicates silicosis.

i. The absence of deaths from silicosis *per se*, tuberculosis apparently always intervening.

j. The failure of workers to recover from their condition upon going into non-dusty trades.

k. The high incidence of sickness of a severe nature from causes other than tuberculosis.

l. The rising sickness and mortality rates from tuberculosis due to longer use of the hand pneumatic tool.

m. The appallingly high death rates at the present time from tuberculosis, compared with normal industrial experience.

Dust Exposure in the Past.—The question of the approximate magnitude of exposure of all workers in granite cutting processes throughout their period of industrial life is a most important one, if we are to relate this exposure to its effect on health and to have a basis upon which sensible recommendations for future control of the hazard may be constructed.

The use of hand pneumatic tools in granite cutting in the United States first became general approximately thirty years ago. There seems every indication, both from such observations as have been made as to the amount of dust caused by hand tools (not pneumatic) and from the much lower tuberculosis rate found in granite cutting before introduction of pneumatic tools, that the dustiness was very much less than today.

The intensity of exposure during the period since the use of hand pneumatic tools became general is a matter of more or less supposition, except for certain facts which have been gained from a personal study of the industry and from information obtained from the workers themselves. It seems certain that the introduction of pneumatic cutting was gradual, so that there was no abrupt change in dustiness during a short period of time. On the other hand, there is definite information to the effect that there were a smaller number of sheds and greater concentration of workers in these sheds ten or fifteen years ago than is found at the present time. The use of ventilating devices for the removal of dust from surface cutting machines belongs to a still more recent period and there is little doubt that the efficiency of these devices has been improved in recent years. These several conditions would indicate that in the early period of use of the hand pneumatic tool there was probably a greater amount of dustiness, especially in the general plant atmosphere, than exists at the present time. On the other hand, the fact that the dust counts for the hand pneumatic tool operators were taken near the source of dust inclines to the belief that conditions for these operators individually have not materially changed since the introduction of the pneumatic tool.

Practicable Limits of Dustiness.—On the basis of the foregoing statements of the past record of dust exposure of granite workers, if we may accept them in a general way, and of our more accurate knowledge of the present exposure, together with the information obtained from the mortality and morbidity studies, it is possible to form some rough ideas of the limits of dustiness which may be regarded as reasonably safe from a health standpoint.

In estimating such limits considera-

tion must be given to the record of tuberculosis and other sickness in the four dust count groups, each having a known concentration of dust exposure. It was found that the A and B groups showed unmistakable indications of the serious effect of the hazard. In those groups the average dustiness was from 40 to 60 millions of particles per cubic foot of air. Group C, which represented the occupations with a dust count equal to that of the general plant atmosphere, showed an average of about 20 million particles. There was little indication in the study as a whole of any serious effect on the men in this group. The death certificates showed, to be sure, unusually high proportionate mortality from tuberculosis among polishers and lumpers, who fall into group C. Confusion between occupations or change in later life from cutters to a less exacting occupation may explain part or all of the excess. But one would hesitate to be positive that no harm would come to persons working for many years under a concentration of 20 million particles. In group D, where the average concentration was 6 million particles, there was no indication whatsoever of any unfavorable effects on health, either from the physical examinations, from the sickness records, or from such mortality data as were applicable to this group.

From this line of reasoning, the average dust exposure for groups A and B must be considered as definitely harmful to the worker. There remains, then, group C in which, with an average exposure of 20 million particles, there is some question as to the harmful effect, and group D, with an average exposure of 6 million and a limit of 9 million, where no harmful effect is found. Thus it would appear that a safe limit lies somewhere between the amount of dustiness found in groups C and D, or between 9 and 20 million particles.

The Ventilation Problem.—The practicable means of attaining such a limit of dustiness for all workers in the plants lies in the provision of adequate ventilating devices for hand pneumatic tool cutters, so arranged as to remove the dust practically at its source.

A few points of particular importance must be brought out.

First. Observations in certain granite plants located in other cities have shown that local exhaust devices can be economically installed which will reduce the dust count for the dust making occupations to less than 20 million particles per cubic foot of air and the general plant atmosphere to approximately 5 million particles. The cost of the devices installed in these plants was not found to be prohibitive; in fact, the dust problem had been met adequately in these plants with a comparatively small expense. The subject is covered fully in an article which was published in the Public Health Reports,[6] both as to the required amount of air to be exhausted and as to the type of ventilating devices used.

Second. In observations made both in the plants in which the present study was conducted and in the plants in which proper types of ventilating devices had been installed, there is evidence of conclusive nature of the necessity for the maintenance of these ventilating systems in proper running

[6] Bloomfield, J. J.: A Study of the Efficiency of Dust-Removal Systems in Granite-Cutting Plants. U. S. Pub. Health Rep., 1929, *44*, 2505.

order through competent supervision of intelligent foremen or machinists, if the full value of the devices from both an economic and a health standpoint is to be maintained. It is impossible to emphasize this point too strongly. In the poor plants observed in this study, the ventilating equipment was not only of little value, but in the case of many of them, as shown by the comparison of summer and winter dustiness, there was an actual menace to the workers because dust was blown back through the windows when open. Even in the better equipped plants improper placing of exhausts or clogging due to improper maintenance largely negatived the full value of the devices.

Third. From observations in both types of granite plants, it is evident that, in so far as possible, ventilating devices which operate irrespective of the attention or desire of the worker himself are most desirable, and that common sense education of the worker to understand and utilize the devices which are provided for the protection of his health is a vital necessity.

Fourth. By segregating in separate rooms or buildings those occupational processes in which little dust is produced.

Although reference has been made to the studies of Bloomfield in the more modern equipped granite cutting plants, and their success in reducing the amount of dust at its source, namely, in the operation of hand pneumatic tools, it is on this particular phase of the subject that our information is weakest and that there is a vital necessity for additional research work. Fortunately, the Department of Ventilation of the Harvard School of Public Health under the charge of Mr. Philip Drinker has been investigating this problem for the past year, and with this work completed, the problem of the health hazards of the granite industry in America seems well on its way to a solution.

Medical Supervision.—The control of the intensity of dust exposure of granite workers will for the most part solve the important problems of the health hazards in this industry. On the other hand, it would seem wise that a check should be made as to this expected improvement in health conditions by some sort of medical supervision of the workers to prevent the entrance into the industry of individuals more than usually susceptible to tuberculosis, to remove workers from the industry if tuberculosis does develop, and, of most importance, to recognize the development of silicosis among these workers.

This final question is far from being a simple one, since neither this study nor any other observations which have been made with respect to granite cutting in the United States give us information as to the amount of silicosis which may develop without making the worker more susceptible to tuberculous infection.

This study does suggest several broad conclusions which appear to bear on this point. In group D, where there was exposure to small amounts of silica dust over long periods of time, there was no tuberculosis, although silicosis did exist. On the other hand, the group of workers who had left the industry after severe exposure and gone into non-dusty occupations appeared to develop tuberculosis to almost the same degree as workers who remained in the industry. This would

incline to the belief that a moderate amount of silicosis, slow in developing, is not incompatible with a long working life and is not a serious inconvenience to health; but that the contrary is true of a severe exposure even for relatively a short period, and that in these cases removal of the worker from the dusty occupation is of no avail. A clearer understanding of the factors which bear upon the developing silicosis and the susceptibility to tuberculosis must be reached. It is desirable that research work should be continued both in the laboratory and among workers exposed to silica dust, to determine some of the points which have been raised in this summary.

What appears to stand out most clearly is that a maximum of dust exposure, falling somewhere between 10 and 20 million particles per cubic foot of air for the dust making occupations, for a dust which contains from 25 to 35 per cent. of free silica in the form of quartz, is a desirable limit, and that it can be obtained by the use of economically practicable ventilating devices applied to the source of the dust.

A Warning.—The rapid rise in mortality from tuberculosis among granite cutters since the adoption of the hand pneumatic hammer, forming so sharp a contrast with the course of the disease in the general population, is of peculiar significance. It has been found that under the atmospheric conditions existing in these plants, little tuberculosis develops until after twenty years' exposure to the dust, after which period the liability to the disease increases rapidly. It is natural therefore that the full force of the hazard is only just beginning to be felt. Since it may well be that the dustiness of the atmosphere in these plants is less today than in recent years (when larger numbers were employed and less precautions taken), there is something ominous about the persistently rising mortality rate. Justification for this apprehension may be found in the section devoted to workers formerly employed as granite cutters, but afterwards engaged in non-dusty trades, together with similar experiences in other studies. The silicosis has continued to progress even after removal from the dust hazard, and the liability to tuberculosis has not decreased and may have, indeed, become greater. In fact, even if adequate local exhaust ventilation were immediately provided in all the plants to reduce the dust level to a safe limit, it seems evident that the deaths from tuberculosis among workers who have used the hand pneumatic hammer for a long period would continue to occur and that perhaps the death rate would rise much beyond its present level.

A RATIONAL EXPRESSION FOR WET KATA COOLING POWER*

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A LARGE amount of experimental work has been done in order to devise empirical formulas for expressing the rate of cooling of a warm body at constant temperature when covered with a film of water and exposed to the atmosphere, but, as far as I know, no attempt has been made to make these formulas reflect accurately the physical laws that influence the rate of cooling. It is the purpose of this paper to develop a rational formula for the cooling rate from known physical laws.

In the case of a dry body the rate of heat loss depends on the radiation exchange with surrounding objects, and on the rate of conduction into the surrounding atmosphere. The radiation exchange between the walls of a closed space and a relatively small body in the enclosure is given by the following expression (1)

$$\frac{Q_n}{\theta} = A p_e c \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right]$$

$\frac{Q_n}{\theta}$ = Net heat loss per unit of time from hotter body.
A = Area of enclosed body.
p_e = Relative blackness of enclosed body.
c = Black body radiation coefficient.
T_1 = Absolute temperature of hotter body.
T_2 = Absolute temperature of cooler body.

According to Hill, glass and skin are nearly black bodies where long wave lengths are concerned.

Over a short range of temperature, radiation may be expressed as a difference of the first powers of the temperatures as is assumed in Newton's Law of Cooling. Its expression would be

$$E = R(T_k - T_s)$$

E = Heat lost or gained per unit of time per unit of area of enclosed body.
R = Coefficient of black body radiation.
T_k = Temperature of enclosed body.
T_s = Temperature of surroundings.

The work of Langmuir (2) showed that a warm body in air is surrounded by a thin film of stationary air through which the heat passes by conduction. Investigation has shown that almost the entire resistance to heat flow from the body is caused by the film close to the body, and so the solution of problems dealing with the transfer of heat from a solid to a gas entails the determination of the film coefficients of conduction. All the coefficients used in this paper are film coefficients and not the usual coefficients that involve a unit thickness. A film coefficient is a rate of flow through a unit area of the film under consideration.

Air motion past the body thins the film and increases the rate of conduction. After heat passes through the film by conduction it is carried away by convection, and it is by this process

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that the great mass of the air is held at nearly the same temperature in all of its parts.

The rate of heat loss by conduction is given by the expression

$$C(T_k - T)$$

C = Film coefficient of conduction.
T_k = Temperature of body.
T = Dry bulb temperature of air.

The expression for the rate of total heat loss is, then,

$$H = R(T_k - T_s) + C(T_k - T)$$

Radiation and conduction effects must be kept separate because the two processes may not be transferring heat in the same direction and because the transfer by radiation is uninfluenced by air velocity.

When the body is covered with a film of water, radiation and conduction take place into the water instead of into the air, and the rate of heat loss is dependent on the temperature of the water.

The rate at which the body loses heat in a given environment depends on a heat balance, equilibrium being established when the heat that flows into the water from the body is equal to that which the water can pass on to the environment. The temperature of the water is the movable factor that adjusts the balance. This water may be considered as a sort of heat clearing house. The body passes heat to the water by radiation and conduction. The water may lose or gain heat from radiation exchange with the surroundings, it may lose or gain heat from the air by conduction, but it will always lose heat by evaporation if the body is cooling.

What has been said of the dry body in regard to radiation and conduction holds for the water. A new factor is now introduced—evaporation. The "motive force" for evaporation is the difference between the vapor pressure at the outside surface of the water film and the partial pressure of water vapor in the air, which is the vapor pressure at the dew point. The resistance encountered by evaporation is the same stationary film of air that impeded conduction. Moving air past the water thins the air film and increases the rate of evaporation, and so the film coefficient of vapor diffusion is influenced by air velocity.

The heat balance may be expressed as follows

$$n(T_k - T_w) = R(T_w - T_s) + C(T_w - T) + KL(e_w - e) \qquad \text{(Equation A)}$$

n = Combined coefficient of radiation and conduction into the water.
T_k = Temperature of body.
T_w = Temperature of surface of water film.
R = Coefficient of radiation.
T_s = Temperature of surroundings.
C = Film coefficient of conduction into air.
T = Dry bulb temperature of air.
K = Film coefficient of vapor diffusion (weight per unit area per unit of time per unit vapor pressure difference).
L = Latent heat (assumed constant).
e_w = Vapor pressure at surface of water film.
e = Vapor pressure at dew point.

It now becomes necessary to consider the wet bulb temperature. When a wet bulb thermometer has reached a steady position, the heat which comes into it by radiation and conduction is equal to that which goes out by evaporation. The balance may be expressed in the following manner

$R(T_s - T^1) + C(T - T^1) = KL(e^1 - e)$

R = Coefficient of radiation.
T_s = Temperature of surroundings.
C = Film coefficient of conduction into air.
T = Dry bulb temperature of air.
T^1 = Wet bulb temperature.
K = Film coefficient of vapor diffusion.
L = Latent heat.
e^1 = Vapor pressure at wet bulb temperature.
e = Vapor pressure at dew point.

If the thermometer is whirled rapidly, the amount of heat coming in by conduction is increased so much that the radiation exchange becomes negligible and the formula may be written

$$C(T - T^1) = KL(e^1 - e)$$

or

$$e = e^1 - \frac{C}{KL}(T - T^1)$$

The ratio $\frac{C}{K}$ is constant at all velocities, which means that a velocity which doubles the rate of conduction will also double the rate of diffusion of vapor.

The formula given in the International Critical Tables (3) for determining the vapor pressure at the dew point by wet and dry bulb temperatures is, in slightly different form,

$e = e^1 - mB(T - T^1)$ (Equation B)
e = Vapor pressure at dew point.
e^1 = Vapor pressure at wet bulb temperature.
m = A constant which has the value 0.00066 when air velocity is over 3 meters per second.
B = Barometric pressure.
T = Dry bulb temperature of air.
T^1 = Wet bulb temperature of air

From this it is evident that

$$\frac{C}{KL} = mB$$

the assumption being that L is constant.

If pressures are expressed in inches of mercury and B is taken as 29.92, and temperatures are in degrees Fahrenheit, the value of mB and so of $\frac{C}{KL}$ is 0.011.

In the main Equation A of steady state, multiply and divide the last term by $\left(\frac{C}{KL} \div \frac{C}{KL}\right)$. This will give

$$n(T_k - T_w) = R(T_w - T_s) + C\left[(T_w - T) + \frac{1}{\frac{C}{KL}}(e_w - e)\right]$$

Substitute for the value of e its equivalent from Equation B, to give

$$n(T_k - T_w) = R(T_w - T_s) + C\left[(T_w - T) + \frac{1}{\frac{C}{KL}}\left[e_w - e^1 + mB(T - T^1)\right]\right]$$

Since $mB = \frac{C}{KL}$

$$n(T_k - T_w) = R(T_w - T_s) + C\left[T_w - T + \frac{e_w}{mB} - \frac{e^1}{mB} + T - T^1\right]$$

The dry bulb temperature disappears. The value of $\frac{1}{mB}$ is $\frac{1}{0.011} = 91$. Substitute this, and the formula becomes

$$n(T_k - T_w) = R(T_w - T_s) + C\left[(T_w - T^1) + 91(e_w - e^1)\right]$$

Temperatures are in degrees Fahrenheit, pressures in inches of mercury,

and coefficients in British thermal units per square foot per hour per degree of difference in temperature.

This equation of dynamic equilibrium or steady state shows that if the wet bulb is held constant, the cooling of the wet body is independent of the dry bulb temperature. If wet bulb is constant it makes no difference whether heat is coming into the water or going out by the process of conduction because the change in dew point caused by a change in dry bulb, with wet bulb held constant, will always be such that the net heat loss remains constant.

The values of n and R must be determined. These are unaffected by air velocity. The value of C, the coefficient of conduction into air, must be determined for different velocities and particular shaped bodies.

The equation brings out a number of points of interest to the physiologist.

Hot conditions can be improved in four ways—by cooling the surrounding objects, by shielding the body from radiant heat, by increasing air velocity, and by lowering the wet bulb temperature.

The equation shows why a given air velocity does not increase the rate of cooling of a wet body in so large a proportion as it increases the rate of cooling of a dry body. If the value of C is increased the temperature of the water drops, and so the values of t_w and e_w are decreased—a fact which tends to nullify the effect of the increase of C. Experience has shown that comparatively little is to be gained by increasing velocities to over 500 feet per minute.

For constant temperature of surrounding objects and constant wet bulb temperature, the rate of cooling is independent of relative humidity. Lowering the relative humidity increases the rate of evaporation but not the rate of cooling. This is governed by the temperature of the water, which remains constant.

With low relative humidity and dry bulb above the body temperature, parts of the body might become dry. In that case heat would flow into the dry parts by conduction.

Cooling by the air ceases when the temperature of the sweat and the wet bulb temperature are the same. Evaporation still goes on at this point but the heat is supplied from the outside. Evaporation ceases only when the temperature of the sweat and the temperature of the dew point are the same.

Attempt should be made to keep the wet bulb temperature as low as possible. The wet bulb may be lowered by removing from the air either sensible or latent heat, or both. The first process entails lowering the dry bulb temperature, and the second lowering the dew point and removing the condensed water.

The amount of water evaporated from the body cannot be used to evaluate heat loss from the body if heat is coming into the water from any source other than the body.

In case the temperature of surroundings and dry bulb temperature are below the body temperature, the sum of the latent heat carried away by evaporation and the heat carried away from the water film by conduction and radiation is a measure of the heat loss.

Summary

A rational formula has been developed for wet kata cooling which takes

the form of an equation of steady state.

The rate of cooling of a body at constant temperature, and covered with a film of moisture, depends on the temperature of the water film into which heat flows from the body by radiation and conduction.

The external conditions that influence the temperature of the water film are wet bulb temperature, temperature of surrounding objects, and air velocity.

With constant wet bulb temperature, the temperature of the water film is independent of relative humidity.

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J. I H.
April, 1930

THE QUANTITATIVE MEASUREMENT OF HUMAN EFFICIENCY UNDER FACTORY CONDITIONS

(*Concluded*)

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FACTORY EXPERIMENTS

METHODS USED

Although in the laboratory one can make a continued and close study of the activities of any one person, it is of course impossible to break into the work of the factory employee at too frequent intervals. One can, however, make less frequent observations on a larger number of persons, without upsetting the working routine of the department. It was found that taking two or three minutes out of every hour to get blood pressure and pulse rate readings was a disturbing influence to only a very few workers. In approaching a new department the usual procedure was to appear once or twice in the days preceding the actual work, explain the process briefly to each worker, and take one or two readings, so that everyone knew what to expect. Apparently even the initial appearance of an unknown observer caused little apprehension because the average of these initial readings was seldom much above the average for the next day. It was found in practice that a single observer could make hourly readings on from six to eight workers, going to them at their jobs and in some cases getting the readings while they were actually at work. In laboratory experiments involving heavy muscular exertion there is a very rapid drop in blood pressure and pulse rate immediately after cessation of work, and the necessity of taking readings during exercise is obvious. In factory situations it would be desirable to do so, but it is seldom possible. Since the readings are so much lower, the inaccuracies due to a pause of from thirty seconds to a minute are unimportant. It is almost always possible to get readings at the job. In only two cases was it necessary to make workers move away any distance.

AVERAGE CURVES

Height of Curve as Index of Energy Expenditure

If a group average is taken, the effect of individual differences in blood pressure and pulse rate is minimized. These differences were found to be considerable, and in some departments the number of subjects was not great enough to make it certain that the actual height of the pulse product measured energy expenditure alone.

TABLE 13.—AVERAGE FIGURES FOR PULSE PRODUCT AND OTHER DATA FOR DIFFERENT FACTORY GROUPS

GROUP	PULSE PRODUCT		TYPE OF WORK	POSITION	LENGTH OF WORKING DAY	SEX	AVERAGE AGE	AVERAGE WEIGHT	NO. OF WORKERS
	Average	Standard Deviation							
		±			*hrs./min.*		*yrs.*	*lbs.*	
1	4,073	323	Inspect and fold clothing	Standing; no chance to move about	8/45	F.	23.2	121	4
2	4,058	269	Machine shop	Various	9/45	M.	29.7	145	9
3	3,878	699	Coil winding	Sitting	8/45	F.	....	...	3
4	3,604[1]	290	Coil winding	Sitting	9/45	"	23.2	...	5
5	3,490	194	Mule spinning	Standing and walking	9/45	M.	....	...	6
6	3,484[1]	411	Mica splitting	Sitting	9/45	F.	33.0	128	5
7	3,146[1]	296	Bench hands, electrical apparatus	Sitting	9/45	"	23.3	...	6
8	3,085	198	Power sewing machines	Sitting	8/45	"	22.0	114	3
9	3,061	382	Stenographers (task and bonus system)	Sitting	7/25	"	26.5	127	6
10	3,041[1]	376	Relay assembly (test room); no rest periods	Sitting	8/45	"	20.8	120	5
11	2,941	382	Gaiter conveyor	Standing and sitting	7/30	"	20.5	127	22
12	2,890	272	Winding (textile mill)	Standing, but with many interruptions	9/—	"	29.2	131	5
13	2,803	276	Quarter room, rubber shoe factory (piecework)	Sitting	7/30	"	25.7	117	6
14	2,664	334	Stenographers (weekly salary)	Sitting	7/—	"	24.7	110	3
15	2,630	485	Stenographers (weekly salary)	Sitting	7/—	"	24.7	110	3
16	2,627	330	Shoe conveyor (rubbers)	Standing and sitting	8/10	"	20.8	133	10
17	2,615	216	Relay assembly (test room); two rest periods	Sitting	8/45	"	20.8	120	5

18	2,581	364	Quarter room, rubber shoe factory; team work	Sitting	7/30	"	21.0	132	6
19	2,553	769	Rubber shoe makers (bench); team work	Standing and sitting	8/—	"	22.5	122	8
20	2,353	257	Stitching machines, rubbershoe factory	Sitting	7/30	"	18.5	114	2
21	2,348	310	Shoe conveyor (rubbers)	Standing and sitting	8/10	"	21.7	131	7
22	2,316	299	Shoe conveyor (rubbers)	Standing and sitting	8/10	"	20.6	136	8
23	2,250	287	Gaiter makers (bench); team work	Standing and sitting	8/—	"	35.0	173	3
Average..	2,978	349					24.2	126.9	140 (total)

[1] Blood pressures taken by company doctor.

Sometimes an entire department is made up of persons more or less of a type. For example, in the rubber shoe factories the bench workers are apt to be fat, middle-aged women, while the workers on the recently introduced conveyors are almost all young girls. In spite of these inaccuracies, the height of the average pulse product was found to be a useful index of the energy expenditure of the department. Table 13 summarizes the readings made in a number of factories. An examination of the types of work listed there shows that the pulse product is a good measure of energy expenditure, not only for muscular work, but also for work demanding high concentration. The highest figure of all is in a department where girls stood still in front of coils, an operation which takes one spot all day long. The next highest is that of a group of men doing heavy muscular work in a machine shop. The third and fourth highest figures belong to groups of girls winding coils, an operation which takes little muscular effort and which allows the workers to sit, but which demands close and sustained concentration. In the higher groups are found the workers who are paid by the hour and those who, although paid by the piece, are given a certain easy daily "ticket" to complete, are all in the lower ranges. The lowest figures are those for the fat, middle-aged and rather easy-going bench workers in a shoe factory.

It is an interesting point that all the workers under team systems, where a certain pace is set for an entire group either by some one individual or by a mechanical belt, have a lower than average pulse product, even where the

work involves considerable muscular exertion. It might be assumed that Group 11, for example, would have about the same figure as Group 1, for they seem to be doing about the same sort of muscular work. In Group 1, however, every worker is setting her own pace under a task and bonus system, while in Group 11 the pace is set by the mechanical conveyor. It seems probable that in such "paced" operations the speed, having been set to permit the slower workers to keep up, allows the average to work at an easier rate than they would if setting their own pace.

The possible involvement of chronic fatigue as a factor in these low figures for the conveyors must be considered. The individual pieceworker can, so to speak, "take a day off" now and then, by turning out a poorer production than usual. These daily fluctuations may be considerable and cannot be regarded as abnormal. The worker who is geared to a conveyor, however, must turn out the same production day in and day out. It is a question whether such machine-like regularity may not, in the case of the slower and less able workers, produce a condition of chronic fatigue. Observers during the War found that as soldiers wore themselves out in the trenches their pulse product almost always fell, because of lowered systolic pressure and pulse rate, and perhaps because of increased diastolic pressure (18). In a few cases the girls working on the conveyors seemed pretty well worn out when the day was over, and perhaps these particular workers had a low pulse product more because the job was too hard for them than because, as in the case of the better workers, it did not demand a high level of energy expenditure.

The remarks apply particularly to Groups 16 and 22, and it was in this factory that the conveyors seemed to have the highest turnover of labor.

It seems hardly probable, however, that enough workers would remain on their jobs, when worn out to this extent, to make their readings seriously distort the averages.

Practical Use of Pulse Product

If one takes the average pulse product as an index of energy expended, and production records as indexes of output, it is possible, wherever the latter can be put on a comparable basis, to measure the relative efficiency of different groups, or of the same group under different conditions.

Example 1. Two Different Groups, Using Different Processes

a. Group 11 makes gaiters on a conveyor.
Group 19 makes rubber shoes on a bench.
One pair of gaiters equals 2.14 pairs of rubber shoes.[3]

Group 11 makes thirty-six pairs of gaiters per worker per day, with an average pulse product of 2,941. Group 19 makes sixty pairs of rubber shoes, which is equivalent to twenty-eight pairs of gaiters per worker per day, with an average pulse product of 2,553.

Although the conveyor is evidently demanding a greater degree of energy expenditure, it is using this energy more efficiently, for the increase in production from bench to conveyor is 28.6 per cent., while the increase in pulse product is 15.2 per cent. One

[3] This equation is taken from the time studies of the factory.

cannot give an exact figure for the difference in efficiency, because no curves are available to show the exact relation between an increasing pulse product and an increasing energy expenditure. Figure 1 showed that in the higher ranges of exertion the pulse product increases more rapidly than at more moderate levels. A percentage increase in production, however, nearly twice that of the increase in pulse product could hardly be obtained without greater efficiency in operations.

b. Group 16 makes shoes on a conveyor, the speed of which gives each worker eleven and one-half seconds to work on each shoe.

Group 21 works on a similar conveyor, the speed of which allows twenty seconds per shoe.

The operations are, of course, subdivided more finely in the first group, which has ten workers, than in the second group, which has seven.

One pair of Group 16 shoes equals 1.103 pairs of Group 21 shoes.

Group 16 makes 109.1 pairs per girl per day, with an average pulse product of 2,627 and an average deviation of ±330. Group 21 makes 87.5 pairs, equivalent to 96.5 pairs of Group 16 shoes per girl per day, with an average pulse product of 2,348 and an average deviation of ±310. The production of Group 16 is, then, 13 per cent. higher than that of Group 21, while its pulse product average is 12 per cent. higher. In other words, although Group 16 has a higher production per girl, the increase is derived from a corresponding increase in energy expenditure, and not from an increase in efficiency. In this case, further subdivision of labor was merely complicating the work of the planning department without increasing the efficiency of the worker. Moreover, although records as to the quality of the product were not available, it is probable that the high speed conveyor turned out more "seconds." During the late afternoon it became more and more difficult to maintain the speed, and unscheduled stops and "skipped jacks" occurred with greater frequency.

Example 2. Same Group Working under Different Conditions

Group 17 was working eight and three-quarters hours each day, with a fifteen-minute rest period in the morning and a ten-minute rest period in the afternoon.

Group 10 comprised the same girls working eight and three-quarters hours with no rest periods. Under these conditions there were twenty-five more working minutes.

With rest periods these girls produced 527.9 units of product per girl per day with an average pulse product of 2,615 and an average deviation of ±216. Without rest periods, production was 556.1 units per girl per day with an average pulse product of 3,041 and an average deviation of ±376. The increase in production amounted to 5.3 per cent. when the rest periods were abandoned, but the pulse product increased 16.3 per cent. The schedule including rest periods therefore seems to bring about the most efficient work.

In the last two examples the working conditions that produced the greatest output were not those conducive to the highest efficiency. Theoretically it is, of course, quite possible that the laziest persons or groups might have a high efficiency, if they used very effectively what little energy they spent. But when production is already at a reasonable height, to increase it still further, at the cost of efficiency, may be

an undesirable speeding up which will eventually result in fatigue and its accompanying unrest and discontent.

Fluctuations in Average Curves

There seems to be no correlation between the height of the average curves for pulse product and the extent of diurnal variations, expressed in terms of standard deviation.

There are certain diurnal fluctuations, however, that appear in the average curves with considerable regularity. Perhaps the most pronounced of these is the rise in pulse product due to eating. This is most noticeable after lunch, but because of the fact that many workers come to the factory in the morning with little or no breakfast it may also appear after a morning rest period, when they have had a chance to visit the canteen. The usual causes of an increased pulse product after meals are a higher systolic pressure, an increased pulse rate, and a lower diastolic pressure. The increased pulse rate is almost always found; the other changes are not so uniform.

Other factors causing diurnal fluctuations involve the changing adjustment of the individual to his work. The most important factors are summarized in Table 14.

The net effect of all these factors is an average curve that falls throughout the day, except for the rises caused by eating. The factors that would cause an increase in pulse product are not so apt to affect all workers at the same time as are those causing a decrease.

TABLE 14.—FACTORS CAUSING DIURNAL FLUCTUATIONS IN AVERAGE CURVE OF PULSE PRODUCT

FACTOR CAUSING FLUCTUATION	EFFECT ON AVERAGE CURVE OF PULSE PRODUCT
Taking of food.	Decrease, after the initial rise.
"Warming up" to work. Production increasing, energy expenditure dropping.	Decrease.
"Speeding up," perhaps in a final spurt. Increase in both energy expenditure and production.	Increase, if all workers in group were in unison, but this is seldom true.
"Slowing down." Decrease in both energy expenditure and production.	Decrease, if workers all slowed down together. This often happens just before stopping.
Emotional disturbance. Decrease in production, increase in pulse product.	Increase, in an individual's curve, but not likely to affect an average.

A question frequently asked is: What effect has fatigue on the diurnal variations in pulse product? The inquiry seems to assume that there is some sort of entity known as fatigue, which can be distinguished from other factors affecting the organism, and which can be shown to have an independent effect on it. The search for a test that would reveal such an entity has always proved fruitless (19), and a better approach to the question involves the concept of continued

efficiency or equilibrium. Decreased nervous integration, inability to fix and sustain attention, and, finally, emotional disturbances are typical symptoms of the fatigue that occurs in light muscular and mental work, and are better measured by changes in efficiency than by changes in production or in energy expenditure alone. Diminished efficiency might go with either a rise or a fall in pulse product,

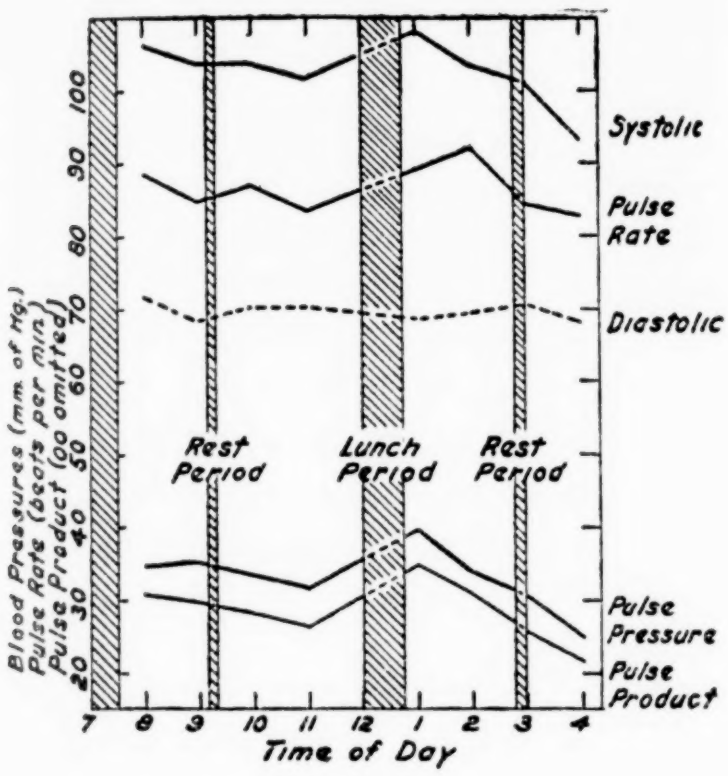

FIG. 6.—Diurnal variations in average curves for twenty-two workers in one factory department.

Averages: systolic, 104; pulse rate, 86.9; diastolic, 70; pulse pressure, 34; pulse product, 2,941; standard deviation, ± 382.

depending on the output that such an energy expenditure could produce.

In Figure 6 are shown the average curves for the twenty-two workers in Group 11. These curves were chosen as typical illustrations of diurnal fluctuations because they are based on a larger sample of workers than any of the other curves; because the average pulse product falls almost at the average of all the groups observed; and because the group worked on a conveyor where the output per hour was practically constant, a working situation almost analogous to the laboratory treadmill.

These curves show that the diurnal fluctuations observed by Weysse and Lutz in sedentary workers also occur in higher levels of exertion, when the load is kept constant.

Conclusions

In average curves the absolute height is significant in measuring the energy expenditure of a group.

The average curve for pulse product tends to drop throughout the day, as a result of the wearing off of the effect of meals, and of the natural reaction to the day's work. Fatigue shows itself in a decrease in both efficiency and production.

INDIVIDUAL CURVES

Factors Involved in a Day's Work

In considering the daily efficiency of any one person, there are four chief factors to consider:

1. Amount of energy expended (represented roughly by the height of the pulse product).
2. Variations in this energy expenditure (represented by fluctuations in the pulse product).
3. Amount of production obtained (represented by both quantity and quality of product).
4. Variations in this production.

Amount of Energy Expended

It is possible to use the average pulse product of a group of individuals as a measure of their collective energy expenditure, with an accuracy which

increases as the number in the group approaches a fair sample of different constitutions. In comparing the curves of individuals, however, the average height will vary not only according to the demands of the job,

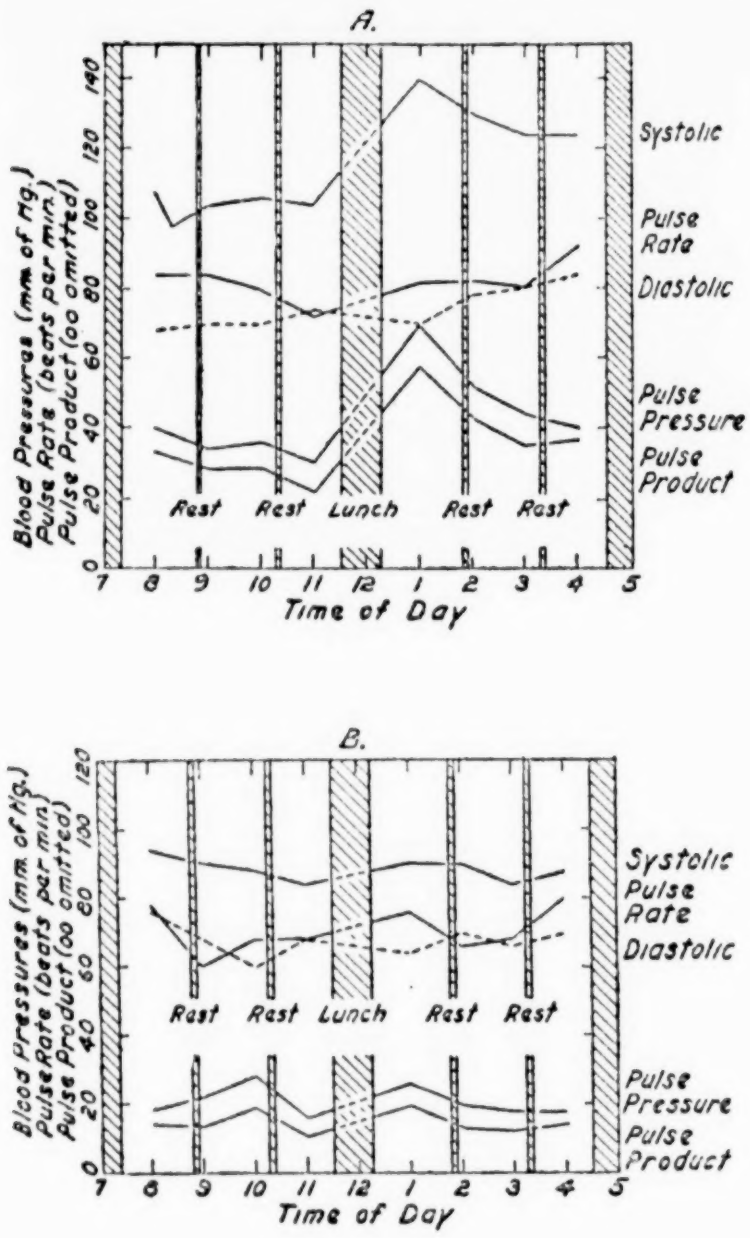

FIG. 7.—Diurnal variations in curves of two girls doing same work.

A = Subject Mary D., energetic. Averages: systolic, 117.5; pulse rate, 82; diastolic, 74.3; pulse pressure, 43.2; pulse product, 3,357; standard deviation, ± 1,033.

B = Subject Josephine, slow and placid. Averages: systolic, 88.5; pulse rate, 70.5; diastolic, 67.8; pulse pressure, 20.7; pulse product, 1,459; standard deviation, ± 296.

but also with the constitutional differences between workers. An example of this is shown in Figure 7. These two girls were both doing the same work on a shoe conveyor. Mary D. was the more experienced, and was most highly regarded by the management. She gave the impression of superabundant vitality, was continually laughing and joking with everyone near her, and did more than her share of the work which was supposed to be equally divided between herself and Josephine. Two weeks after our visit she left the plant to become an operator in a beauty parlor, and it was discovered that she had for some time been attending a night school for hairdressers and masseurs.

Josephine was a fat, placid Italian, who, although she had been working on the conveyor long enough to have learned her job, was still on the beginner's rate. Had it not been for Mary's help, she could not have kept up the pace. Her slowness apparently caused her no concern. Her figure for pulse product was the lowest ever observed, while Mary's was the high figure for this group.

There is no doubt that Mary was spending much more energy than Josephine, not only on her work, but in singing, talking, and doing dance steps in slack moments. However, her resting pulse product also would undoubtedly have been higher. The energy expenditure that found expression in work (either useful or wasted) was but a symptom of a more active organism.

Although these are two extreme cases, they show the need for caution in interpreting the height of a worker's pulse product. It may not depend on the demands of the job alone.

Variations in Energy Expenditure

In the group averages, diurnal varia-

tions reflect influences that are affecting the entire group, but the fluctuations of a single curve may not correspond. As was shown in the laboratory experiments, the smoothest curve at a given level of exertion shows the most effective expenditure of energy. In the factory, one cannot pick out the best worker by a low fluctuation in pulse product alone, for he might also be the laziest.

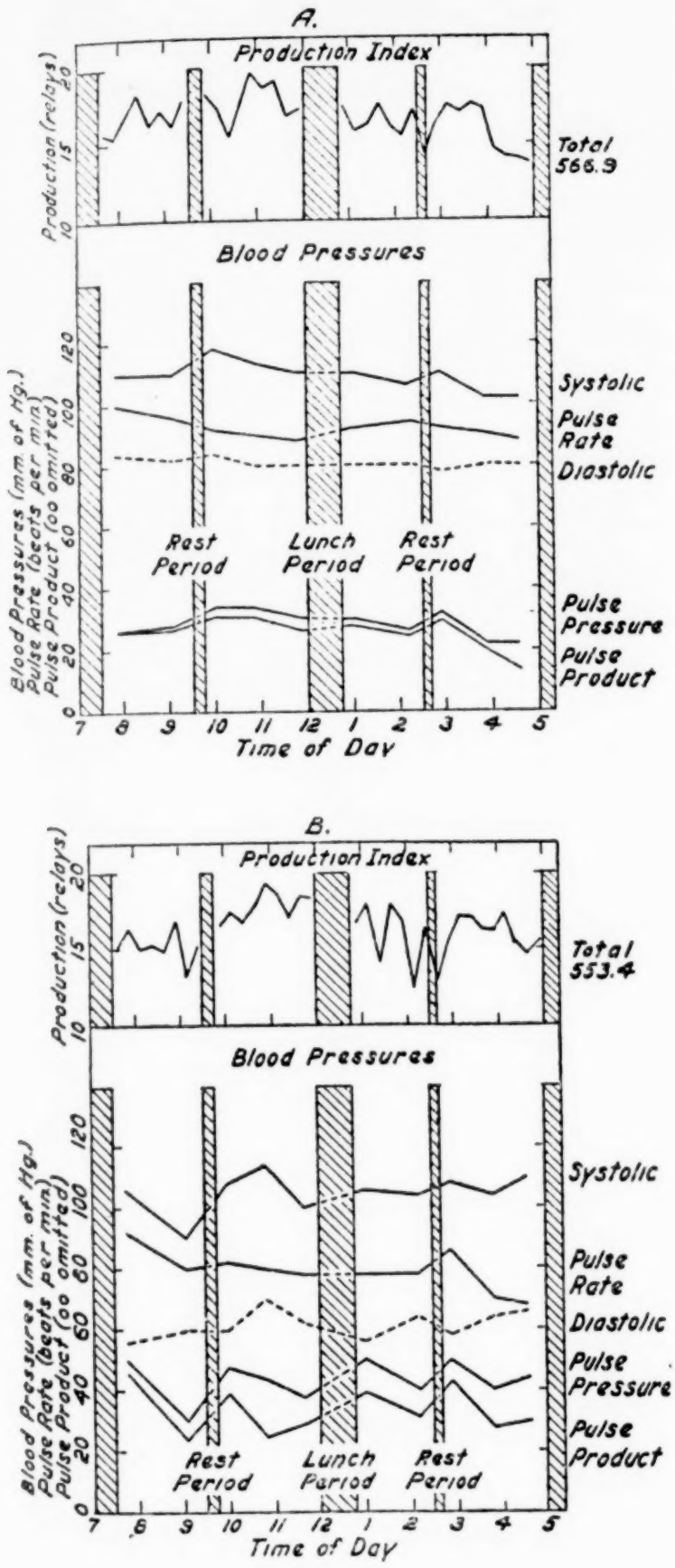

FIG. 8.—Diurnal variations in curves of four workers of different types

A = Subject Jennie, skilled and efficient. Averages: systolic, 109.2; pulse rate, 92.2; diastolic, 80.8; pulse pressure, 28.4; pulse product, 2,617; standard deviation, ± 386.

B = Subject Mary V., strenuous and fairly efficient. Averages: systolic, 105; pulse rate, 79.2; diastolic, 61.6; pulse pressure, 43.4; pulse product, 3,353; standard deviation, ± 730.

C = Subject Anna, phlegmatic but fairly efficient. Averages: systolic, 102.3; pulse rate, 77; diastolic, 71.8; pulse pressure, 30.5; pulse product, 2,357; standard deviation, ± 373.

D = Subject Mary G., unskilled and inefficient. Averages: systolic, 113.3; pulse rate, 98.3; diastolic, 63; pulse pressure, 50.3; pulse product, 4,970; standard deviation, ± 1,138.

There is also a difference in type of worker; the phlegmatic person has fewer emotional fluctuations than the more excitable. What might be perfectly normal fluctuations for the latter, might indicate acute distress for the former. There is, therefore, no correlation between high figures for absolute height and deviations in energy expenditure. Production records are necessary before one can come to any conclusion as to the worker's efficiency.

Figure 8, for example, shows the daily curves for four workers who may be ranked in the following order:

A. *Jennie:* high production; even energy expenditure; high efficiency.

B. *Mary V.:* high production; uneven energy expenditure; fairly high efficiency. Because of an organic condition it was not so easy for her to turn out a high production as it was for Jennie.

C. *Anna:* low production; even energy expenditure; good efficiency. She was of the phlegmatic type, not spending the energy that the first two did.

D. *Mary G.:* low production; uneven energy expenditure; low efficiency; fatigue and emotional distress.

Figure 9 shows the curves for the same worker on two occasions, the first one (A) an average day, and the second (B) a day when efficiency was low (due to menstruation). It is interesting to note that the height of the pulse product was almost the same in both cases, but on the second day this amount of energy was not so well spent, as is shown by the wide fluctuations in the curve and by the low production.

Amount of Production Obtained

This factor in the measurement of efficiency can be obtained from production records. For our purposes it is necessary to consider the *quality* of the work turned out as a part of the *amount* of production. The maintenance of a certain grade of work is as much a function of a capacity to sustain effort as is the mere number of

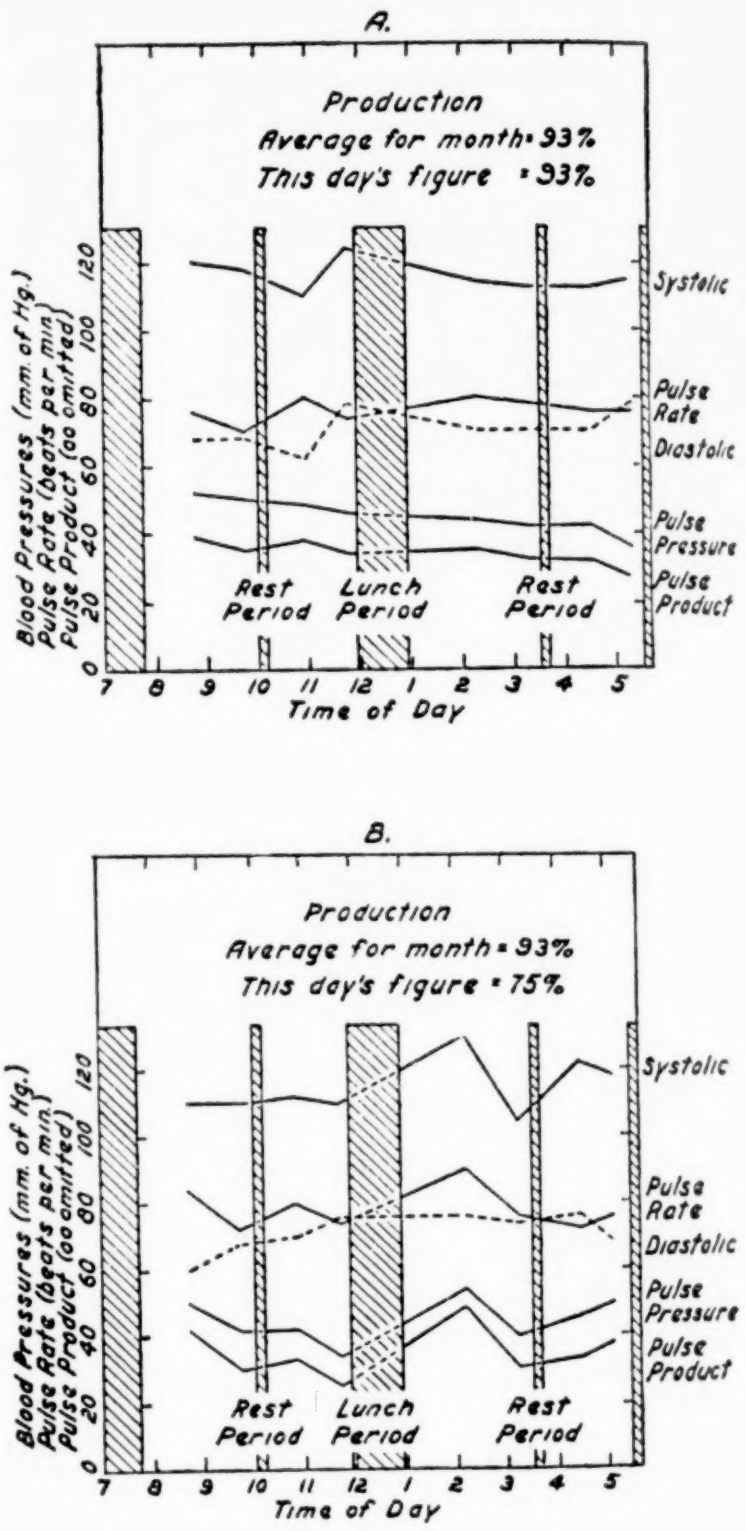

FIG. 9.—Variations in curves of subject Rose on two different days.

A = Efficient day's work. Averages: systolic, 115.5; pulse rate, 76.3; diastolic, 70.5; pulse pressure, 45; pulse product, 3,427; standard deviation, ± 350.

B = inefficient day's work. Averages: systolic, 115.7; pulse rate, 78; diastolic, 71; pulse pressure, 44.7; pulse product, 3,490; standard deviation, ± 694.

pieces produced. A diminished quality shows progressing inefficiency even though the numerical output remains high.

In actual practice it is hard to get adequate production records which show both quantity and quality of work, and which are in comparable terms. Wherever different units of production are reduced to the same terms by means of time studies, it seems to be assumed that the average day's work of a good workman in one job demands the same exertion as in another, because the equation between different units is always derived from production records alone. At best, these equations can be no more than approximations.

Variation in Production

The measurement of daily production figures will reveal gross changes in working capacity. Shorter period fluctuations are equally significant, and represent the steadiness with which effort is sustained. There is no reason to assume that the worker who has a regular daily output measured over a period of several days is necessarily the most even worker throughout the day.

Short period fluctuations in exertion would be lost, of course, even in hourly production records, and no method has yet been devised of getting a continuous record of energy expenditure other than by measuring production. In the case of one department, however, it was possible to get accurate figures by fifteen-minute intervals, where the production time of each unit was only about one minute. It was thus possible to compare workers as to:

a. Short period fluctuations in output (fifteen-minute intervals).

b. Daily fluctuations in output (measured over a period of several weeks).

c. Actual output for the particular day when short period fluctuations were measured.

d. Actual output per day during the period when daily fluctuations were measured.

TABLE 15.—AMOUNT OF PRODUCTION IN A SINGLE DAY AS RELATED TO SHORT PERIOD FLUCTUATIONS IN PRODUCTIVITY[1]

WORKER	HEIGHT OF PRODUCTION	SHORT PERIOD FLUCTUATIONS IN PRODUCTION
	%[2]	%[2]
W_1	108.5	133.0
	102.8	158.3
	99.6	119.2
W_2	111.8	158.8
	105.3	140.9
	102.4	114.9
W_3	93.0	80.1
	96.0	86.0
	99.5	91.8
W_4	98.5	69.1
	100.5	55.2
	100.5	99.0
W_5	88.2	58.9
	95.5	59.6
	98.0	75.0
Coefficient of correlation.....		+0.7479

[1] Each pair of figures represents a day's work of one person.

[2] Of group average.

These comparisons are shown in Tables 15 and 16. The data in Table 15 give a coefficient of correlation of +0.7479 and show that the best workers have the highest short period fluctuations in production. Not only is this true for different workers, but the same worker will have a higher fluctuation on the days when she

produces the most. A high level of energy expenditure cannot be maintained without frequent short periods of slackness, and the resulting variations in production, instead of indicating a lack of organic equilibrium in the best workers, are necessary for the maintenance of that equilibrium.

TABLE 16.—AMOUNT OF PRODUCTION OVER A PERIOD OF SEVERAL WEEKS AS RELATED TO FLUCTUATIONS IN DAILY OUTPUT[1]

WORKER	HEIGHT OF PRODUCTION	FLUCTUATIONS IN DAILY OUTPUT
	%[2]	%[2]
N_1	87.5	102.3
N_2	99.4	80.1
N_3	108.4	118.9
N_4	99.7	56.0
N_5	104.2	72.0
N_6	102.3	147.2
N_7	98.6	123.6
W_1	104.8	97.5
W_2	108.0	156.6
W_3	97.3	71.2
W_4	97.1	82.2
W_5	92.7	92.7
M_1	105.8	102.5
M_2	91.4	83.1
M_3	108.7	67.6
M_4	106.6	50.3
M_5	87.4	196.6
Coefficient of correlation.....		−0.2240

[1] Each pair of figures represents the work of one person over a period of from two to six weeks.

[2] Of group average.

The data in Table 16, which include additional figures from other departments, have a coefficient of correlation of −0.224 and show that even a high fluctuation in daily figures when compared with the average for a longer period does not *necessarily* distinguish a bad worker, although there is a *tendency* for the better workers to have the more even production.

In the face of such a conclusion as to short period fluctuations it may seem strange that the conveyor belt is so successful in modern industry. Not only has it increased production, but many workers seem to prefer it. As a matter of fact a conveyor, set at a proper speed, allows all but the slowest worker a breathing space between each piece. This does not mean that the worker finishes each ahead of time and then stands idle for a moment, but the possibility of short period variations is not lost. The fact that many workers alternately spurt and relax is lost sight of in the general feeling of steady movement which the conveyor gives to an observer.

Conclusions

In individual curves both absolute height and fluctuation of the pulse product may reflect constitutional differences between workers, as well as the demands of the job. This fact must be remembered in interpreting pulse product curves as indexes of energy expenditure.

The most efficient workers not only have a high output per unit of energy expenditure, but maintain organic equilibrium at higher levels of exertion. In high speed work, frequent short periods of slackness are necessary to maintain this equilibrium, and a high fluctuation even in total daily production from day to day does not necessarily distinguish a poor worker.

Further Comparisons of Factors Involving Variation in Efficiency

As between Different Workers

Because the efficiency of no two persons is the same, when one com-

pares members of a group there is no correlation between the amount of energy expended and the output attained. In the typewriting experiment discussed above, it was found convenient to classify four types of work that might occur during the day of any one worker; the same classification may be useful in characterizing the total day's performance of any one person when comparing him with another. In Table 17, for example, a number of workers have been grouped in this way. Those of the first type

TABLE 17.—COMPARISON OF WORK OF DIFFERENT GROUPS OF PERSONS

TYPE	NO. OF WORKERS	ENERGY EXPENDITURE[1]	PRODUCTION	VARIATIONS IN ENERGY EXPENDITURE[2]	CHARACTERIZATION OF WORK
		%[3]	%[3]	%[3]	
1	13	89.8	107.8	83.3	Skilled.
2	5	112.5	107.3	108.3	Strenuous.
3	8	87.3	94.6	87.4	Sluggish.
4	12	113.5	90.1	122.2	Unskilled.

[1] Pulse product.
[2] Standard deviation of pulse product.
[3] Of department average.

were selected because they had a lower than average energy expenditure and a higher than average production for the day in question. When thus chosen, it was found that their average fluctuation in pulse product was also low. This confirms the conclusion that the most efficient workers not only have a high production per unit of energy expenditure, but maintain equilibrium at this level of exertion. The other types were likewise selected for the relation between energy expenditure and production. The corresponding averages for fluctuations in energy expenditure also confirm this conclusion. The most inefficient workers have the highest fluctuations.

The figures from which this table was derived represented the day's work of particular persons. The same person may vary from one day to another as to position in this grouping. Thus, the girl illustrated in Figure 9 moved from type 1 to type 4 on the day when she was unfit. Such comparisons are useful, therefore, in indicating any change in the condition of particular workers. They are also useful in directing attention to workers who regularly fall into a particular classification. When one examines the records of the workers who day after day fall in type 4, for example, one finds that they include most of those classified by their superiors as problem employees, either because of physical handicap or because of emotional instability.

As between Different Periods of the Day

In the case of the department where fifteen-minute production records were available, it was possible to make a study showing roughly diurnal variations in working efficiency. There were wide variations between individuals, but an average for all workers for three days is shown in Table 18. Each day was divided into ten periods. Each worker's energy expenditure and production were expressed, for each period, as a percentage of her day's average. These periodic figures were then averaged for the department as a whole. The group was working under practically ideal conditions, and its morale was very high. This fact is confirmed by the shape of the effi-

TABLE 18.—DIURNAL VARIATIONS IN EFFICIENCY OF A SINGLE DEPARTMENT[1]

PERIOD	TIME	(A) ENERGY EXPENDITURE[2]	(B) PRODUCTION	EFFICIENCY (B ÷ A)	CHARACTERIZATION OF WORK
		%[3]	%[3]	%	
1	7:30– 8:15	105.5	97.5	92.4	Unskilled.
2	8:30– 9:15	93.2	101.0	108.4	Skilled.
3	9:45–10:30	104.3	101.1	96.9	Strenuous.
4	10:45–11:30	95.5	103.7	108.6	Skilled.
5	11:30–12:00	100.9	101.9	101.0	Strenuous.
6	12:45– 1:30	109.5	96.6	88.2	Unskilled.
7	1:45– 2:30	103.6	96.6	93.2	Unskilled.
8	2:45– 3:30	101.1	102.1	101.0	Skilled.
9	3:45– 4:30	91.4	102.4	112.0	Skilled.
10	4:30– 5:00	90.2	99.6	110.4	Sluggish.

[1] Average figures for five workers for three days.
[2] Pulse product.
[3] Of day's average.

ciency curve, in which the only important depressions are caused by the effect of meals, and the need for "warming up." (The girls ate a lunch during their morning rest period, which accounts for the drop in efficiency in the third period.) These figures have not been corrected for the effect of meals, and it is doubtful whether the actual efficiency was lowered as much as they indicate. The drop in production after lunch, however, is quite noticeable.

Because of the lack of reliable short time production figures, we have no study of diurnal fluctuations in a department where working conditions are bad. Probably under such conditions the late afternoon drop in the efficiency curve would be more marked and would begin earlier. This does not necessarily imply that the pulse product would be higher, unless emotional distress were general, but production would probably fall even faster than pulse product, and the efficiency figure would be low.

Summary

The measurement of human efficiency demands quantitative estimation not only of a worker's production, but of the energy used in attaining it. For practical use under factory conditions some simple method of measuring energy expenditure is needed.

The pulse product increases directly with the amount of energy used in muscular work. It also increases in emotion, and in efforts of attention. Properly interpreted, it is useful as an index of energy expenditure, and its determination is practicable under working conditions in office and factory.

The efficient worker not only has a high production per unit of energy

expenditure, but maintains organic equilibrium as exertion increases. Lack of such equilibrium in muscular work will be shown not only by an increase of lactic acid in the blood, but by an unduly high and irregular pulse product. Ordinary factory work is not heavy enough to cause any increase in lactic acid, but the height and fluctuations of the pulse product, combined with production records, can be used to distinguish variations in efficiency when comparing departments, workers, or different periods in the day. Measurements of energy expenditure, and of efficiency, when made in this way, are applicable not only to muscular work, but to work involving attention and concentration.

Fluctuations in production are natural, and in some cases are necessary to maintain efficiency. The best worker is not necessarily the one with the smoothest production curve.

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(For bibliographic references numbered less than 18, see the first instalment of this article in the preceding issue of This Journal.)

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BOOK REVIEW

INDUSTRIAL MICROSCOPY. By *L. C. Lindsley*, Ph.D., Formerly Head of Department of Chemistry at the College of William and Mary; Professor of Industrial Microscopy, Department of Chemical Engineering, Columbia University Summer School; Industrial and Research Chemist. Cloth. Pp. 286 with index and illustrations. Richmond, Va.: The William Byrd Press, Inc., 1929.

"Industrial Microscopy" will meet with instant approval by many investigators in industrial hygiene. In this field there is increasing need for more refined methods in the investigation of industrial dusts and fumes. The stone cutting industry with its many problems of dust evaluation and disposal as related to silicosis, and many metallurgic processes, as well as numerous other dusty trades, offer problems which are solvable only by means of the microscope. And this increasing application in turn has emphasized somewhat specialized phases of microscopy. Dr. Lindsley's book should prove particularly valuable to all who are interested in the composition of dusts or fibers, in particle sizing, or in the analysis of material too minute in amount for the usual type of chemical analysis.

The scope of the work is best illustrated by enumerating the main divisions. The first four chapters discuss (1) The Microscope, (2) Crystals, (3) Chemical Microscopy, and (4) Qualitative Analysis (by means of the microscope). The remainder of the book is devoted to specialized chapters on (5) Common Alkaloids, (6) Analysis of Common Textiles, (7) Pulp Woods and Papers, (8) Identification of Common Starches, (9) Micrometry, and (10) Minerals and Rocks.

The chapter on crystals—a subject difficult to compress satisfactorily—is especially well written and summarizes in simple language the salient points of optical mineralogy. A few well-chosen experiments are given to illustrate difficult points. Because of the complexity of the subject to the average student and because of its increasing practical importance, this section could be profitably elaborated somewhat in a future edition.

Extensive tables are included which give indexes of refraction of liquids, hardness of minerals, and melting points of organic substances arranged for the most part by one-degree intervals from 10° to 302°C. Microchemical tests are given for a number of elements including many metals not encountered in the usual course in qualitative analysis, but none the less important. The text is abundantly illustrated with excellent photomicrographs.

This book will be found useful by all who have occasion to use the microscope, and particularly by those investigators whose work occasionally takes them into the field of chemical microscopy.—*Lawrence T. Fairhall.*

J. I. H.
April, 1930